

Access Selection and Pricing in Multi-Operator Wireless Networks

Soha Farhat

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Access Selection and Pricing in Multi-Operator Wireless Networks

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A toi maman,

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Résumé

La cinquième génération de réseaux mobiles, 5G, est destinée à prendre en charge le besoin croissant en bande passante, l'accroissement du nombre de mobiles connectés à des équipements et l'évolution des services attendus par les usagers. Il est prévu que la 5G fournisse une capacité beaucoup plus grande que la quatrième génération (4G) pour répondre à la demande croissante des utilisateurs, suite à l'apparition de multiples nouveaux services. En fait, le volume de données échangé devrait d'ailleurs être multiplié par 1000 avec le nombre croissant de terminaux connectés. La 5G a aussi pour objectif de permettre l'explosion attendue de l'internet des objets, accompagnant les nouveautés comme les villes intelligentes, les voitures sans conducteur ou les systèmes de soins de santé. On envisage un grand nombre de capteurs, machines industrielles et de transport connecté ayant besoin d'une connexion ubiquitaire et à tout moment. La 5G devra être un réseau mobile à ultra haut débit et peu consommateur en ressources énergétiques. Différentes technologies se complèteront mutuellement pour atteindre les objectifs de la 5G. En fait, la densification des antennes du réseau est un des moyens pour renforcer la capacité des réseaux mobiles contre la croissance du trafic. De plus, le déploiement de petites cellules comme des métrocellules, des picocellules et des femtocellules, présente une solution économique permettant d'accroître encore la capacité et réduire la consommation d'énergie, grâce à des modalités intelligentes d'orientation et de délestage du trafic. En outre, l'exploitation de bandes de fréquences plus élevées, les techniques de non-orthogonalité et les antennes multiples, associés au partage du spectre, sont des facteurs clés pour parvenir à une plus grande efficacité spectrale. Le passage à la 5G imposera des changements non seulement dans le réseau d'accès radioélectrique mais aussi dans le réseau central, où les solutions logicielles joueront un rôle essentiel pour assurer la connectivité à un nombre croissant d'utilisateurs et de dispositifs. La tendance actuelle est de découpler le matériel du logiciel et de faire migrer les fonctions du réseau vers le logiciel, afin de réaliser une séparation entre la commande et les données. Ainsi, des efforts de normalisation visent à définir la virtualisation des fonctions du réseau. En conséquence, avec une exploitation plus simple, de nouvelles caractéristiques du réseau seraient déployées plus rapidement. Dans certains pays, la 5G devrait en effet être lancée commercialement pour 2020. C'est pourquoi, les opérateurs mobiles devraient continuer d'investir, dans les prochaines années, dans le déploiement de leurs réseaux mobiles à très haut débit, qui vont leur permettre d'augmenter les débits et d'adapter la capacité des

réseaux à la hausse exponentielle du trafic. En effet, pour déployer ce futur réseau mobile, beaucoup d'argent a déjà été mis sur la table principalement chez Huawei et Samsung, par la Commission Européenne, par la partie privée du 5GPPP et par la Corée du Sud. Dans ce contexte, certains régulateurs comme l'Arcep trouve que les accords de partage de réseaux mobiles peuvent constituer pour les opérateurs un moyen d'accélérer et de réduire les coûts de déploiement tout en améliorant leur offre de services. Ainsi, parmi les caractéristiques essentielles des futurs réseaux mobiles, on compte une capacité accrue, de moindres dépenses d'investissement et d'exploitation, une ubiquité complète assurée par un interfonctionnement multinorme ainsi que le partage du spectre et de l'infrastructure. Le partage de réseaux mobiles consiste à mettre en commun entre plusieurs opérateurs tout ou partie des équipements constituant leurs réseaux mobiles. On distingue deux grands types de partage d'infrastructures actives : l'itinérance qui consiste en l'accueil, par un opérateur de réseau mobile, des clients d'un autre opérateur de réseau mobile sur son réseau, pour lequel seules les fréquences de l'opérateur accueillant sont exploitées. Et, la mutualisation des réseaux qui contrairement à l'itinérance, exploite les fréquences des deux opérateurs. Notre travail se situe dans le contexte de partage de réseau mobile actif, ou un nombre d'opérateurs partagent leur accès radio, afin de former un system multi-technologie multi-opérateur. Dans cet environnement coopératif, un utilisateur mobile peut être servi à travers le réseau de son opérateur de domicile, avec lequel il a fait un contrat, ou il est transféré par son opérateur de domicile pour être servi à travers le réseau d'un autre opérateur coopérant. Ce dernier déterminera le coût de transfert, qui sera payé par l'opérateur du domicile de l'utilisateur. Le but de notre étude est de montrer les avantages de la coopération entre les opérateurs, principalement en ce qui concerne les revenus. De plus, nous cherchons des stratégies pour surpasser les conséquences négatives du partage des ressources, surtout celles touchant la performance des réseaux des opérateurs coopérants. Nous avons montré que les bénéfices de la coopération dépendent fortement du choix de partenaires, la tarification de service (cout de transfert) entre les partenaires, et combien un opérateur partage de ses ressources.

Notre travail consiste, en premier temps, à proposer un algorithme de sélection d'accès applicable dans un réseau multi-opérateurs. Cet algorithme devrait garantir la satisfaction en QoS de l'utilisateur et celle en profit de son opérateur d'accès à l'Internet. Ainsi, un algorithme adoptant une décision hybride, NP-BPA (Nearest Performance and Best Profit Algorithm), est proposé. Il exploite la simplicité des algorithmes MADM (Multiple Attribute Decision Making), spécifiquement SAW (Simple Additive Weighting), et l'efficacité de l'approche NPH (Nearest Performance Handover). Cet algorithme de sélection est basé sur une fonction de coût combinant les exigences du service de l'utilisateur mobile, et le profit résultant du transfert de l'utilisateur à un autre opérateur. La comparaison de performance de notre algorithme, NP-BPA, avec d'autres méthodes MADM, comme SAW et NPH, a montré son efficacité concernant la probabilité de blocage et le profit global réalisé. Notre algorithme de décision garantit la plus faible probabilité de

blocage pour tous les opérateurs comme il évite les surcharges du réseau. En outre, NP-BPA donne aux opérateurs la possibilité d'exprimer leur stratégie lors de l'exécution de la sélection, et ainsi faire du contrôle d'accès tout en utilisant deux coefficients explicites dans la fonction de coût.

En deuxième temps, nous étudions la tarification de service entre les opérateurs partenaires, précisément le coût de transfert d'un utilisateur. Ce dernier paye juste le prix du service que son opérateur d'accès à l'Internet détermine, il est inconscient du transfert. Les modèles de tarification proposés relient le coût de transfert d'un opérateur au prix adopté pour le service des clients. Le premier modèle, ACAG (As Client As Guest), suggère que le coût de transfert d'un opérateur soit égal à son prix de service. Le deuxième modèle, MIWC (Maximum Income When Cooperating), suggère que les coûts de transfert des opérateurs coopérants soient identiques, et égaux au prix de service le plus élevé des partenaires. Et, le troisième modèle, MCWC (Minimum Cost When Cooperating), suggère que les coûts de transfert des opérateurs coopérants soient identiques et égaux au plus petit prix de service des partenaires. L'étude de la profitabilité de ces modèles dans un system à trois opérateurs, et la comparaison au modèle de partage de prix, ont montré que nos modèles garantissent les profits les plus élevés, et assurent le partage de profit entre les partenaires en respectant leur capacité partagée. La décision du meilleur modèle à adopter lors de la coopération, intervient une interaction entre les différents partenaires. Nous avons modélisé cette interaction à l'aide de la théorie de jeux. Nous avons exploité un jeu Stackelberg à deux niveaux, TPA (Transaction Pricing and Access Selection), où les opérateurs de service agissent comme Leaders et les opérateurs d'accès à l'Internet des utilisateurs à transférer agissent comme Followers.

Finalement, nous avons considéré le mode d'accès hybride pour la coopération. Ce mode d'accès est proposé comme solution surtout pour les opérateurs partageant la plus grande capacité. La performance du réseau de ces opérateurs est relativement affaiblie suite à la coopération. Nous avons vérifié que le pourcentage de blocage diminue quand l'opérateur, ayant une capacité élevée, réduit le pourcentage de ressources partagées. Pour un même pourcentage de partage, le profit d'un opérateur diffère avec le modèle de tarification adopté. Ainsi, une bonne décision doit être prise, concernant le pourcentage de partage et le modèle de tarification, tout en tenant compte de l'effet de cette décision sur les autres partenaires du système. C'est pourquoi que nous avons proposé un nouvel jeu séquentiel à deux niveaux, RS-TP (Resource Sharing and Transaction Pricing) afin de modéliser l'interaction entre les opérateurs, pour le partage de ressources et la tarification du coût de transfert.

Abstract

5G networks will rely on virtualization and network sharing in order to address the explosive growth of broadband traffic mobile, the increasing number of mobile connected devices and the evolution of mobile user expectations. Network sharing is a powerful approach that helps to reduce the deployment time and cost of a new radio access network, expand coverage, accelerate the integration of a new technology and to optimize resource utilization. Further, it is efficient for new revenues achievements.

We consider a roaming-based infrastructure sharing system, where multiple operators share their radio access in a multi-operator environment. In such system, mobile users can access the base station (BS) of their home operator or the base station of another partner of the sharing system. We assume that all BSs of the partners remain active and the users are not free to access another operator BS without the permission of their home operator. Indeed, when the home operator of a user is unable to satisfy its constraints, because of lack of resources or QoS, a transaction event is triggered. It consists in transferring the considered user to another operator in order to access the service. Moreover, when there are more than two operators sharing their access, the user transfer process includes an access selection decision in order to choose the best operator for service. We assume that the access selection decision is triggered and controlled by the home operator of the transferred user. Furthermore, when a user is transferred, its home operator must pay some transaction cost as cooperation fees for the new service operator. This transaction is seamless to the user. Therefore, the inter-operators sharing agreement set for cooperation must include three important issues: the selection decision algorithm, the transaction cost pricing scenario, and the percentage of resources shared by each operator.

In the first part, we introduce our selection decision algorithm in a multi-operator environment, NP-BPA (Nearest Performance and Best Profit Algorithm). It is based on a multi-criteria cost function which groups the different parameters that enable a satisfying selection decision, for the operators and users. In this decision process, the home operator of the transferred user is the main player, it triggers and performs the selection applying its own strategy using our cost function. We show the efficiency of our selection algorithm in different environments considering different numbers of partners. Besides, the performance of NP-BPA algorithm was compared to MADM (Multiple Attribute Decision Making) methods, precisely SAW (Simple Additive Weighting), and NPH (Nearest Performance Handover), in a three operator environment. NP-BPA showed better re-

sults for the blocking rates and global achieved profits. Our algorithm helps to reduce overloading situations for the service operators; its distributes the transferred users in an efficient manner and thus improves the profits for all cooperating partners.

In the second part, we study the transaction cost. We find rational that an operator sets its transaction cost as a function of its service price. First, the service price is a public parameter that can be easily exchanged with other partners. Second, if an operator decides to vary its service price or to adopt dynamic pricing, it will affect directly the transaction cost. We consider a sharing system of three partners, interacting to decide the best transaction cost. Taking into account that the service of a guest user may affect the probability of acceptance of a client, an operator looks for preserving the expected revenue from its client. Therefore, we propose the first pricing scenario, ACAG (As Client As Guest) that aims to set the transaction cost of an operator equal to its service price. However, every operator seeks to maximize its revenue; therefore it is expected to set a higher transaction cost. How much higher? This must respect the sharing agreement between different partners and the service prices they adopt. To be optimistic, we propose a second pricing scenario MIWC (Max In When Cooperating). With this scenario all partners agree to have a transaction cost equal to the highest service price announced in the system. But, this scenario may cause losses in some cases where an operator setting a low service price performs a lot of transactions. To be fair, we propose a third pricing scenario MCWC (Min Cost When Cooperating). With this scenario all partners agree to have a transaction cost equal to the lowest service price announced in the system. Although this pricing scenario seems "hypothetical", it is more profitable than ACAG, in some systems.

Next, to study the profitability of these pricing scenarios we presented two system models: In the first system, the operators set the same pricing scenario but share different capacities. In the second system, the operators share the same capacity but set different service prices. In both systems we compare the achieved profits using our pricing scenario and price sharing scenarios. Results show that the best pricing scenario for an operator depends on its shared capacity and the service price it sets. Besides, one pricing scenario may maximize the profits of one operator but not of the others. Hence, to decide the best pricing scenario to adopt in the sharing system, a two stage Stackelberg game, TPA (Transaction Pricing and Access Selection) game, is formulated. In this game, the operators are the players; the service operators are the leaders and the home operator of a transferred user is a follower. Two cases were studied: the first one where all operators adopt the same pricing scenario. In this case we found the U-TPA (Uniform Transaction Pricing and Access Selection) equilibrium. And, the second case where each operator adopts its own pricing scenario. In this case we found the F-TPA (Free Transaction Pricing and Access Selection) equilibrium. In both cases the equilibrium scenario is MIWC. In fact, in the system where the partners share different capacities and set different service price, MIWC guarantees the best profit sharing among all partners.

In the third part, we consider a three operator sharing system with hybrid access mode. In this system partners decide to share a restricted amount of their capacity. We show how the sharing factor affects the blocking rates and affect the global profits. Further, the achieved profit does not depend only on the sharing factor, but also on the adopted pricing scenario. Therefore an economic framework based on game theoretical analysis is proposed. It models the interaction between the sharing system operators for resource sharing and pricing, in addition to the access selection. A sequential game is formulated, RS-TP game (Resource Sharing and Transaction Pricing), where the players are the operators. In the first stage, the sharing partners decide the proportion of resources they will share and the transaction pricing scenario in order to maximize their own profits. In the second stage, the home operator of a transferred user selects the suitable service operator. A bi-level optimization problem is solved and equilibrium is found.

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Nomenclature

3GPP	3rd Generation Partnership Project
5G	Fifth Generation
APs	Access Points
BBU	Baseband Processing Units
BS	Base Station
C-RAN	Cloud Radio Access Networks
CAPEX	CAPital EXpenditure
CC-CRRM	Cloud-Computing based Cooperative Radio Resource Management
CRRM	Coordinated Radio Resource Management
D2D	Device-to-Device
ESS	Evolutionary Stable Strategy
F-TPA	Free Transaction Pricing and Access Selection
H-CRAN	Heterogeneous Cloud Radio Access Networks
H-op	Home operator
HetNet	Heterogeneous Networks
MADM	Multiple Attributes Decision Making
MIMO	Multiple-Input Multiple-Output
MNOs	Mobile Network Operators
MSP	Macro Cell Service Provider
MVNO	Mobile Virtual Network Operator

NFV	Network Function Virtualization
NP-BPA	Nearest Performance and Best Profit Access
OPEX	OPerational EXpenditure
RAN	Radio Access Networks
RS-TP	Resource Sharing and Transaction Pricing
S-op	Service operator
SCNs	Small Cell Networks
SCSP	Small Cell Service Provider
SDN	Softaware Defined Network
SLA	Service Level Agreements
SPs	Service Providers
TPA	Transaction Pricing and Access Selection
U-TPA	Uniform Transaction Pricing and Access Selection

Chapter 1

Introduction

1.1 Motivations

Fifth generation mobile networks must address new challenges that appeared with the explosive growth of the mobile traffic broadband, the increasing number of mobile connected devices and the evolution of mobile user expectations. In fact, global mobile data traffic grew 74 percent in 2015 and it is expected to increase nearly eightfold between 2015 and 2020 [Ind16]. In addition, mobile users are more aware of the QoS and are evaluating increasingly the connectivity, especially for the services with high QoE expectations. The need of high-speed connectivity for anything, anywhere and anytime is growing, and operators are facing the challenge to upgrade their network in order to expand capacity, support higher data rates and enhance QoS in terms of End-to-End (E2E) latency with energy and cost efficiency. Further, the growth of data consumption is overtaking voice usage [Eri15, Mar11], thus affecting operator's revenues. Consequently, new strategies are needed for new network deployment or the rollout of 5G technology, that helps operators to keep up with the mobile market and ensure additional incomes.

5G mobile technology promises innovation for entire mobile industry [HUA13, 5GP15, NGM15]. It targets massive capacity and connectivity in order to support an increasingly diverse set of services, applications and users with extremely diverging requirements. It aims for a flexible and efficient use of available radio resources. Future mobile networks will adopt new solution frameworks to accommodate both LTE and air interface evolution, as Cloud, SDN and NFV technologies. The roadmap of 5G includes a number of network and technology solutions as [YOU15, AIS+14, 5GP15]:

- The use of millimiter-wave frequencies and Massive MIMO for maximum transmission data rates 20 times as fast as 4G LTE.
- The use of full duplex radio technologies and Device-to Device (D2D), in order to improve the downlink spectral efficiency.
- The deployment of small cell and heterogeneous network architecture [BLM+14].

- The use of efficient inter-cell interference management for ultra-dense networks.
- Radio Access network Virtualization in a Cloud-based radio access infrastructure [GiC16][CCY+15].

An important step in defining 5G has already been made in the Next Generation Mobile Networks (NGMN) [NGM15] where 25 use cases have been identified, grouped into eight use case families, and serve as input for specification of requirements and defining the building blocks of the 5G architecture.

For operators, time and cost are crucial. Therefore, a rational decision have to be done in order to hold on with the mobile market evolution. And, since the growth of traffic and revenues are decoupled, new sources of revenues and new cost reduction solutions are needed. RAN (Radio Access Network) sharing is a rational approach that can help to reduce costs, to maximize efficiency and competitiveness, and to enhance customer satisfaction. It is introduced as a cost effective solution to expand coverage and increase capacity in [Cor13, Joh07, FSL14, JG13]. It involves active sharing of RAN between two or more operators as a mean of mutually offering access to each other's resources. This inter-operators arrangement brings a lot of benefits for operators as CAPEX and OPEX savings, new revenues achievements and energy consumption reduction. Besides, it promotes innovation since the competition between operators, in such environment, is based on offered services and features [MGM13]. In fact, current 3rd Generation Partnership Project (3GPP) standards fully support network sharing between operators under different sharing scenarios as Multi-Operator Core Network (MOCN) and Gateway Core Network (GWCN) [rGPP13].

Nowadays, a key factor for achieving infrastructure sharing is the virtualization of physical entities by decoupling their functionality from the hardware. Further, network densification and small cell deployment are achievable through virtualization in H-CRAN; femtocells and picocells are created by RRHs instead of low power base stations (BS) and access points, the infrastructure workload is computed at the BBU, where resource availability as well as overloading of physical entities becomes easier to assess [MKGM+15].

1.2 Problem Statement

We consider an infrastructure sharing system, where multiple operators share their radio access in a multi-operator environment. This environment includes RAN virtualization and also a Cloud based radio access infrastructure. In such system, mobile users can access the BS of their home operator or the BS of another partner of the sharing system. We assume that all BSs of the partners remain active and the users' access to another operator BS is controlled by the home operator. Indeed, when the home operator of a user is unable to ensure its satisfaction constraints, because of lack of resources or QoS, a transaction is triggered to transfer the considered user to another service operator and

the access to the service is granted through the network of this operator, thus avoiding the user rejection.

Accordingly, every operator have to adopt a suitable strategy for serving the users of another operator (guest users) without affecting its network performance or its own subscribers satisfaction. Actually, the hybrid access mode is the most promising because it allows operators to give preferential access to their own subscribers, while other guest users can only access a restricted amount of resources. Besides, when there is more than two operators sharing their access, the transaction process includes an access selection decision in order to choose the best operator to serve the user. The access selection decision is triggered and controled by the home operator of the transferred user. In fact, in a multi-operator environment, a hybrid approach for the selection decision is a need, in order to guarantee the user satisfaction and the operators happiness in the same time, especially when considering the cost to pay for the transaction. In fact, when transferring the user to a new service operator, some transaction fees must be paid to this operator. The home operator has to make this payment, in order to keep this transaction seamless to the user.

Therefore, the inter-operatorss sharing agreement set for cooperation must include three important issues:

1. The selection decision algorithm adopted in the sharing system.
2. The transaction fees, characterized by a transcation cost for each operator.
3. The percenatge of resources shared by each operator.

We assume that a third trusty party is integrated in order to maintain and guarantee the inter-operators agreements especially for the transaction cost pricing.

1.3 Thesis Organization

The remaining of this thesis is organized as follows: A survey on RAN sharing is introduced in Chapter 2. We discuss the benefits of a RAN sharing and reveal the main challenges of a successful sharing agreement. In addition, we investigate the radio access selection decision in a multi-operator environment, and classify a wide range of methods, using simple mathematical tools, including Multiple Attributes Decision Making (MADM), Fuzzy and Game Theories.

Moreover, different strategies for the inter-operators service pricing are represented, it includes the different business models that may be adopted during cooperation and how to determine the inter-operators service cost between sharing partners. Further, an overview of different modeling frameworks for the access selection and service pricing is made. These models use game theory in order to describe the interaction between the service providers in a multi-operators network.

Chapter 3 introduces our selection decision algorithm, NP-BPA, in multi-operators environment. It is based on a cost function which considers jointly the offered QoS parameter offered by the service operators and the profit of the home operator resulting from the transaction. The performance of this selection algorithm is investigated in different sharing environments considering different numbers of partners. Then a performance comparison is made with MADM methods, precisely SAW and NPH, in a three operators environment. Further, an analysis of two coefficients of the cost function reveals the ability of an operator to express its strategy and to control the access selection decision of its user.

In Chapter 4, the inter-operators service cost is studied and three basic pricing scenarios are proposed. These pricing scenarios determine the transaction cost of an operator as a function of its service price or the service price of other partners in the sharing system. Further, the profitability of these scenarios are compared with other pricing scenarios in litterature that consist of sharing the transferred user payment between its home operator and the new service operator. Moreover, the decision of the best pricing scenario to be adopted in the system is achieved using game theory; the interaction between the operators of the sharing system is modeled using a Stackelberg game where the available service operators are the leaders and the home operator of a transferred user is a follower.

Chapter 5 grabs resource sharing and reservation in a three operator system. It shows how resource reservation can guarantee client satisfaction by reducing the blocking rates. In addition, the inter-operators service pricing and the profitability of the previously proposed scenarios are investigated in a hybrid access mode. Further, an economic framework based on game theoratical analysis is proposed. The framework formulates a two-stages sequentiel game in which the sharing partners decide the proportion of resources they will be shared with other partners, and the transaction pricing scenario to adopt in order to maximize their profits.

Chapter 6 concludes the thesis, where we summarize the main contributions, and present future research directions.

Chapter 2

Access Selection and Service Pricing in Multi-Operator Shared Networks

With the exploisive growth of mobile broadband traffic, the MNOs must consider new measures to upgrade their networks in order to expand coverage, increase capacity and enhance service quality with cost reduction optimization. Network sharing is a powerful approach to bring down network costs on both relative and absolute scale. It involves RAN and networking infrastructure sharing between two ore more mobile operators. In such sharing networks, an agreement must be set between operators for the access selection decision process, the inter-operators service cost and the resource sharing policy to be adopted during cooperation. This chapter briefly introduces the motivations of RAN sharing, the benefits and the challenges to achieve a successful network sharing transcation. And, it presents some exemples of current RAN sharing markets. Furthermore, an overview is made on the access selection decision making approaches, in single and multi-operator heterogeneous networks. Moreover, different strategies for the inter-operators service pricing are represented, it determines the transaction cost between partners.

2.1 Why RAN Sharing?

5G mobile networks must address new challenges that appeared with the explosive growth of the mobile traffic broadband, the increasing number of mobile connected devices and the evolution of mobile user expectations. In fact, global mobile data traffic grew 69% in 2014 [Ind15], and it is expected to increase nearly eightfold between 2015 and 2020 [Ind16]. Besides, the need of high-speed connectivity for anything, anywhere and anytime is growing, and operators are facing the challenge to upgrade their network in order to expand coverage, increase capacity, support higher data rates and enhance QoS in terms of E2E latency, with energy and cost efficiency.

In addition, for Mobile Network Operators (MNOs) the speed of new technologies introduction, the quality of the network and indoor coverage are main factors that in-

fluence a mobile customer decision for the choice of an operator and his willigness to pay for access. Hence, it is necessary to find a cost efficient solution in order to achieve an optimal balance between profits and costs. Network sharing is a powerful approach that can help to accelerate coverage expansion, reduce deployment period and optimize resource utilization. Further, it is efficient for additional CAPEX and OPEX savings and new revenues achievements.

Network sharing consists of RAN sharing, *i.e*, the radio access layer which contains the infrasctructure and the base station subsystem, between two or more MNOs. Typically, RAN represents the one-third of the total OPEX and 80% of CAPEX, and it counts 52% of total indirect network costs [HDT09]. RAN sharing arrangement brings a lot of benefits for operators and it promotes innovation since the competition between operators, in such environment, is based on offered services and features. RAN sharing is a promotive approach when a MNO has already reached the limits of cost improvement. In addition, it is advantageous for operators who seek new investments, as well as in greenfields situations where new technology could require a rethinking/renewal of the network insfrastructure [GSM15].

5G networks will likely rely on RAN sharing [Net15, ASD15], in order to accelerate and reduce the cost of new RAN deployment using, for instance, new millimeter wave spectrum, in addition to sophisticated multi-tower, multi-carrier aggregation.

2.1.1 What to share?

Currently, network sharing is mainly confined to elements of the RAN such as infrastructure and base station subsystem elements [GSM15]. Few sharing deals do include parts of the core networks and spectrum because of regulatory issues that aim to maintain networks capabilities differentiation. Besides the cost benefits of core networks sharing are not as great as the benefits of RAN sharing [GSM15]. Current 3GPP standards fully support network sharing between operators [rGPP13, Net15], it defines three different levels determining how shared networks are integrated. The diagrams in Fig. 2.1 describes the different sharing levels:

1. **Multi-Operator RAN (MORAN)** sharing is where only equipments are shared.
2. **Multi-Operator Core Network (MOCN)** sharing is where both equipments and spectrum are shared.
3. **Gateway Core Network (GWCN)** sharing is equipments, spectrum and some core network elements are shared.

In practical, operators do not share the entire RAN, and can maintain dedicated RAN in the areas where traffic is heavy. Some mobile economics analyst find that RAN sharing is efficient in the markets where most customers have pre-paid service, thus, having more network availability means more billable minutes, thus more revenues.

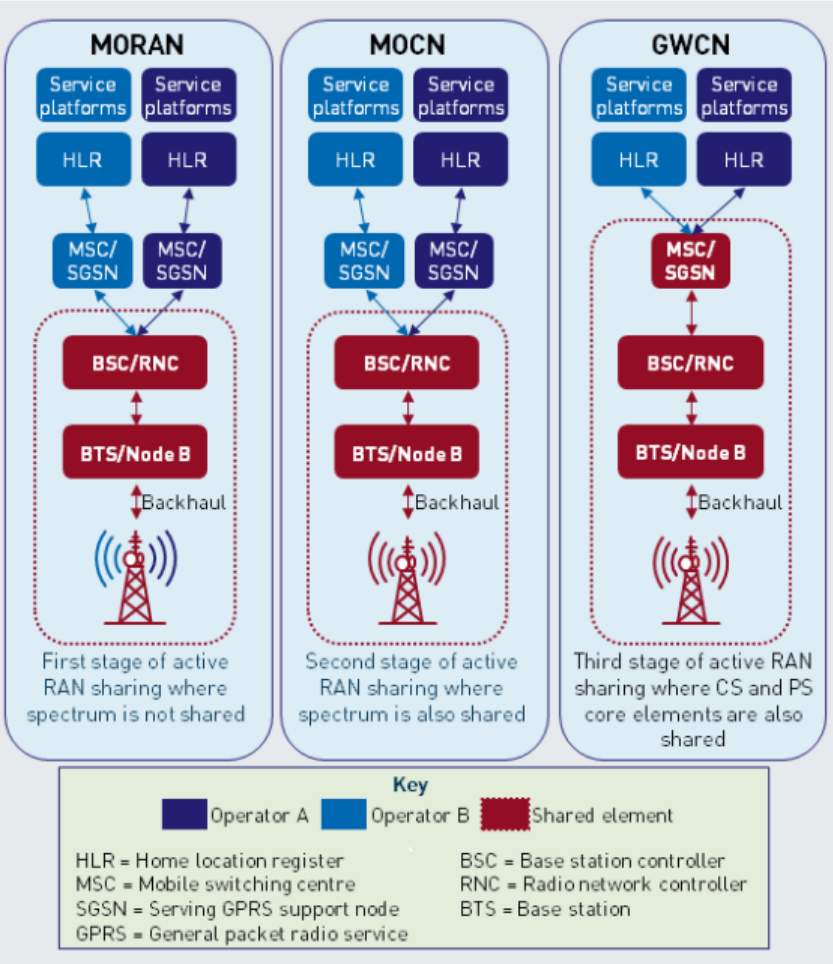


Figure 2.1: RAN Sharing Levels[PO14]

The partnership structure identifies the dimensions of the shared network. According to RADAR approach [HDT09], the sharing network has four dimensions:

1. **Geography**: It determines which locations will be shared urban, rural, selected urban and rural or countrywide.

2. **Infrastructure**: It determines the physical components of the network to be shared, with two sharing categories:

   - **Passive** RAN sharing: where operators share only physical cell sites and towers and passive infrastructure elements like shelters, masts, air conditionning and power supplies.
   - **Active** RAN sharing: where operators share passive equipments as well as transport infrastructure (radio access nodes and transmission), radio spectrum and baseband processing resources. Generally, the RAN sharing is not uniform, passive sharing may be used in some locations and active sharing in others.

3. **Technology**: It determines which mobile capabilities are to be shared 2G, 3G or 4G technology. MNOs might share some combination of these technologies or all of them.

4. **Process**: its determines the services to be shared as:

   - Engineering, planning and design.
   - Deployment and rollout.
   - Optimization.
   - Maintainance and operation.

2.1.2 How to share?

How to share determines the adopted structure for network sharing, it helps to specify the commercial, technical, operational and legal conditions of partnership. Three structures can be used [HDT09]:

1. **New network**: This structure is ideal when rolling out a new network generation, sharing partners build a new network together and share it.

2. **All-in-one network**: This is a non classical network sharing structure, where a MNO provides the network while the others abondon their networks and benefit from wholesale network services from recipient MNO, which may include national roaming and Mobile Virtual Network Operator (MVNO) services. In this structure, the parties agree that one operator will build, own and operate the network in one geographical area and allow others to roam, with the same arrangement in reverse in another geographic area.

3. **Consolidated network**: This structure arise where operators merge their networks and deconstruct the redundant sites. In such structure the asset ownership may be handled by three forms:

   - **Joint Venture**: The ownership is shared in a joint venture, which takes the form of a common company that owns, operates and maintains the joint network. The parent MNOs contribute financial and human resources to this joint venture. The most common structure adopted is the 50/50 joint venture [Hen14]. In fact, when a joint venture is formed for sharing, the operators are almost like MVNOs on the shared network.
   - **Third Party outsourcing**: Where sharing operators transfer their assets and outsource the management and operation of their shared network to a third party. In fact, 25% of the operators entrered this kind of arrangement,

although it reduces the savings and results in (Service Level Agreements) SLA-driven control of the third party as well as loss of competence with the operator's organisations.

- **Network Company**: It is a service company where one operator is the owner of the total network while the others pay for the service.

2.1.3 Benefits of Network Sharing

The first sharing agreement was made in Sweeden between Telia and Tele2, in early 2001. Telia was unable to acquire a 3G licence, so a joint venture on a 50-50 basis was established with here competitor Tele2, and it was able to become a 3G operator without having its own license. RAN sharing occurs as the best option for medium and small sized operators, as well as new operators [Hua11]. It reduces the network deployment period and accelerate the rollout of new technology in order to meet the time frames imposed by regulators. In addition, RAN sharing brings a lot of financial advantages for MNOs [Hen14], it is able to:

1. Reduce the total cost of network ownership defined as the sum of costs to buy, to install, to operate and to maintain a network. In fact, sharing the access layer brings a lot of savings in CAPEX and OPEX. Through sharing, operators are able to save money to find the appropriate site, to deploy the new site, to buy transmission and radio equipments, in addition to maintenance and power costs reduction.

2. Increase revenues resulting from widen service coverage, and wholesale arrangements which boost the return on capital.

3. Promote better utilisation of the network resources, spectrum pooling grants higher spectrum bandwidth and higher data thoughput.

4. Reduce the number of communication towers which scales down the environmental impacts [GSM15] for a green communication.

2.1.4 Challenges of Network Sharing

Four main challenges are to be considered in order to achieve a successful network sharing transaction [Hen14]:

1. **Loss of independency**: When an operator is engaged in a sharing arrangement he risks to lose independency of :

   - The network operation (handover, performance KPIs and baseband capacity split ratio...).
   - The full control over network strategy and investments.

- The rollout strategies and vendor choices.
- The competitive developments with sharing partners in terms of service differentiation.

2. **Partner selection**: With who to share is a very important issue, an operator must consider the following:

   - The number of partners which affects the amount of cost savings in a shared network and the geographical distribution of partners' sites which may cause additional costs of dismantling redundancies in a large overlap.
   - The potentiel of differentiation with other partners. In fact, the sharing arrangement with a partner with a similar network is easier to reach. On the other hand, sharing with smaller or less advanced operator may cause loss of significant competitive advantages.
   - The alignment on network evolution and deployment, and investment plans and strategies with the new partners.

3. **Regulatory issues**: Usually, the degree to which network sharing is allowed and supported by regulators differs by country. Mainly, regulators are concerned to maintain competitive differentiation capabilities and avoid collision. These concerns are generally muted over passive sharing. Network sharing is allowed sometimes for environmental reasons and regulators tend to be more in favor of sharing in rural coverage.

A good sharing legal agreement must detail which entity has a full control over the whole network, how to evaluate assets and how to transfer existing assets into a joint venture structure. In addition, partners must agree on pricing transfer for ongoing services, how revenues are distributed and how operational, rental and power costs are shared.

2.2 RAN Sharing Market

Network sharing is not new, it has been started with national roaming and bilateral site sharing. Since 2001, three trends have emerged. Firstly, network sharing joint ventures between mobile network operators in Sweeden-Europe [Bui15]. A second trend, towerco deals, started in the last six years [Bui15]. It is the most frequent form of sharing around the world, where an operator sells its towers to a third party-or forms a joint venture- and leases them back, the majority of these deals have been in Africa and are taking place in other regions in the world especially in the Americas. A more recent trend is operator consolidation [Bui15]. And, the fourth trend that may emerge the next five years is core network sharing [Bui15], considering the technology developments arising with network function virtualisation and software-defined networking.

The network sharing picture in the Americas has been dominated by 70% of the towerco deals, in Brazil, Chile, Colombia, Mexico and the USA. The only active sharing deals between operators to date have been in Canada and Brazil. Europe is in the first place with 15 active sharing deals but with only three towerco deals to 2015, in France, Spain and Netherlands. Africa leads the world in towerco deals with three multinational operators accounting for more than 80% of the deals. Asia Pacific stands out for its passive sharing between MNOs, operators are engaged in multiple deals as in India and Bangladesh. Some of network sharing deals in Europe, presented in [Bui15] are given in Table 2.1.

Table 2.1: Network Sharing Deals in Europe

Country	MNO1	MNO2	Towerco or Operator 3	Deal Type	Date
Hungary	Telenor	Magyar Telekom		Active	Feb 2015
Germany	Telefonica/E-plus	Drillisch		Active	Jun 2014
Russia	VimpelCom	MTS		Active	Dec 2014
Finland	TeliaSonera	DNA		Active	Aug 2014
France	SFR	Bouygues		Active	Jan 2014
Iceland	Vodafone	Nova		Active	Nov 2013
Netherlands	T-Mobile	Tele2		Passive	Sep 2013
Spain	Telefonica (Movistar)	TeliaSonera (Yoigo)	Abertis	Towerco	Aug 2013
Romania	Vodafone	Orange		Active	Aug 2013
Greece	Vodafone	Wind Hellas		Active	Jun 2013
Netherlands	KPN		Protelindo	Towerco	Nov 2012
France	Bouygues		Antin IP	Towerco	Nov 2012
Ireland	Vodafone	Hutchison (Three)		Passive	Jul 2012
UK	Vodafone	Telefonica (O2)		Active	Jun 2012
Russia	Rostelecom	MTS		Passive	Feb 2012
Poland	T-Mobile (PTC)	Orange		Active	Jul 2011
Denmark	TeliaSonera	Telenor		Active	Jun 2011
Ireland	Hutchison (Three) [formerly Telefonica O2]	Eircom (Meteor)		Passive	Apr 2011
Czech Republic	O2	T-Mobile		Active	Feb 2011

2.3 Access Selection Decision Making in Heterogeneous Networks

2.3.1 Access selection decision in a Single Operator network

Access Selection was widely studied in heterogeneous wireless networks managed by a single operator. Various mathematical approaches that can be employed for access selection are presented and evaluated in [WK13]. Access selection tools include: utility and cost function used in [NVGDA08, OMmM06, BL07, KJ12b], Multiple Attribute Decision Making (MADM) methods in [KJ12b, SJ05, Zha04, HLIK13, SNW06, MMPRSN10, KJ12a, HILK13], Fuzzy Logic in [Zha04, GAPRS05, GAPRS09], Markov Chain in [SJ06, HILK14] and Game Theory in [CSMW02, ZBDH14, SPTC15, AHNK11, AP07, CMT08].

In a cost function based algorithm, decision parameters are normalized, assigned a weight and then injected into a weighted sum to produce a selection score. The decision parameters used for access decision and their utility functions are resumed in [WK13] and represented in Table 2.2. We can distinguish the bandwidth, BER, the delay, the jitter, the price and latency, used with Linear and sigmoidal utility functions.

Table 2.2: Decision parameters and their utility functions

Attribute	**Utility Functions**
Bandwidth	Linear, logarithmic, sigmoidal
Battery	Linear
Price	Linear, logarithmic
latency	Linear
Interruption Probability	Linear
Traffic	Linear, sigmoidal
Power Consumption	Linear
BER	Linear, sigmoidal
Delay	Linear, sigmoidal
Packet Loss	Linear, sigmoidal
Jitter	Linear, sigmoidal
Response Time	Linear
Service Completion Time	Linear, polynomial, exponential

In [GAPRS05] author makes use of a methodology based on fuzzy-neural systems in order to carry out a coordinated management of the radio resources among the different access networks. In [Zha04], the author uses fuzzy logic to deal with imprecise criteria and user preferences; data are first converted to numbers and then classical Multiple Attribute Decision Making (MADM) methods as Simple Additive Weighting (SAW) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), are applied. Another approach aims to prioritize the available RATs to decide the optimum one for mobile users. Such approach was applied in [SJ05], using Grey Relational Analysis (GRA), which

aims to prioritize the networks for the selection decision, after defining an ideal solution. Analytical Hierarchy Process (AHP) was adopted to arrange the decision parameters in three hierarchical levels, in order to calculate the corresponding weighting factors. Another exemple of combining GRA with AHP-based weighting is presented in [WK13]. Figure 2.2 describe how AHP can be used in order to calculate the decision parameters weights, then use them in order to calculate networks coefficients in GRA and make the selection decision.

NPH approach, introduced in [KJ12b], consists of defining the SAW score for the ideal solution, calculates the SAW score for every candidate, and then computes the distances of each candidate score to the ideal solution score. Finally, the access network with the closest score to the ideal one is selected for the service. The ideal solution score is the user's SAW score considering the QoS parameters required by the user's application. In [CMT08], authors use AHP and GRA in order to construct the payoff of requests and achieve network selection using multi-round game.

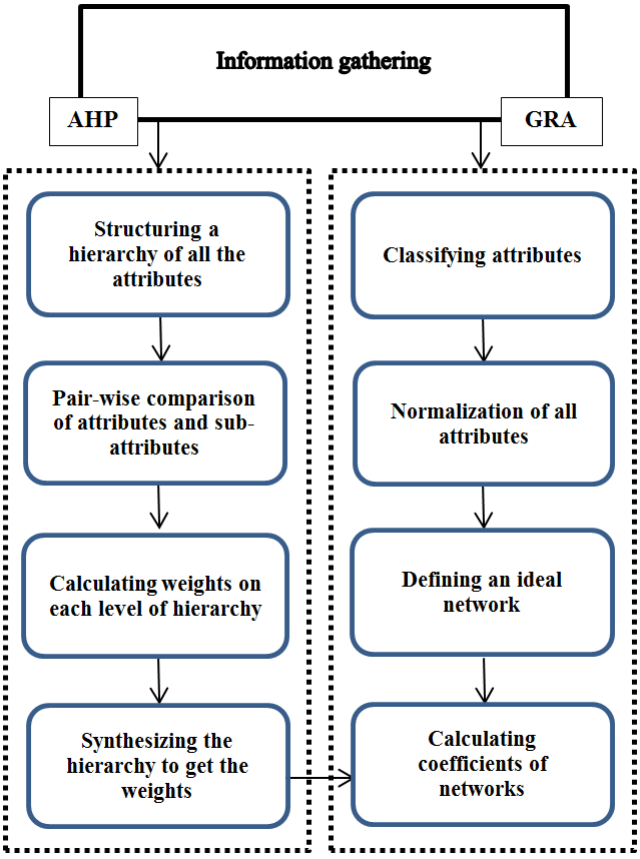


Figure 2.2: MADM with AHP-based weighting

In [SNW06], a performance comparison was made between Multiplicative Exponent Weighting (MEW), SAW, TOPSIS and GRA. Results showed similar performance to all traffic classes. However, higher bandwidth and lower delay are provided by GRA for interactive and background traffic classes. A network centric approach is adopted in

[Tah07], to ensure load balancing, while minimizing the costs of resource underutilization and demand rejection.

In our work, we exploit the advantages of MADM techniques and especially the simplicity of SAW and NPH to develop a novel decision algorithm. Chapter 3, introduces our proposed algorithm, NP-BPA, for the access selection in a multi-operator network environment [FSL14, FSLC14]. Further, in the same chapter a comparison of our algorithm with SAW and NPH is made, results show the efficiency of our decision algorithm a three operators sharing network [FSLC15].

2.3.2 Access selection decision making in a Multi-Operator network

In a multi-operator heterogeneous network, a new "flex service" paradigm was introduced in [FPK+12]. It allows a mobile user subscribed to "Flex service" to dynamically access base stations (BSs) of different providers based on various criteria, such as profile, network conditions and offered prices. "Flex users" can select the appropriate provider and BS on a per-session basis. Authors present two modeling framework for the access markets at both microscopic and macroscopic levels. At a macroscopic level, users are considered as a homogeneous population with respect to preferences and decision-making mechanism. The behavior of users is described by a population game in order to determine how the entire user population reacts to the decision of providers. At a microscopic level, a flex user accesses dynamically base stations of different providers based on various criteria, such as profile, network conditions and offered prices. At this level the modeling framework and simulation platform are based on different modules concerning the providers, the clients and the u-map, that serves as a review/feedback system from users and providers. The overview of the main modules of the microscopic level framwork is presented in Fig. 2.3. The client module contains information about the user service choice, the selected BS, its profile...The user profile determines the user constraints on cost, blocking probability and data rates, in addition to its preferences. And, the provider modules contains the price adaptation and the network blocking probability estimation. In our work, we envisage a similar multi-operator environment, where a user can access the base station of a different provider. However, our considered market is more open than "Flex service" market, since a mobile user does not need any previous subscription as a "Flex user". Besides, the access selection decision is controlled by the home operator; the user is not free to switch between operators.

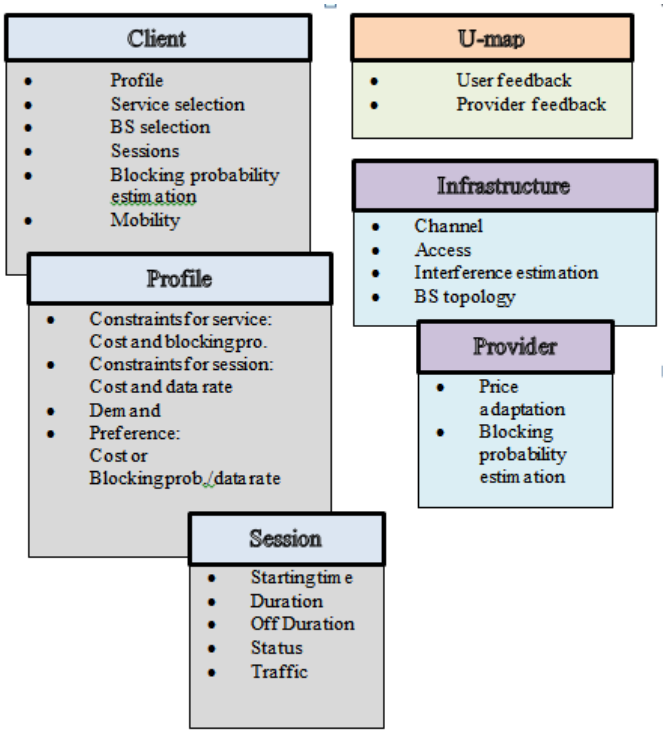


Figure 2.3: An overview of the main modules of the Flex access market

In fact, the majority of the existing works, in multi-operator environment, use game theory for the access selection and the joint service pricing. In [CSMW02], authors applied a non-cooperative game that makes use of Leader–follower model (Stackelberg game) in order to study the competition between two ISPs. With a simple QoS model, a Nash equilibrium point was found from which the two ISPs would not move without cooperation.

In [KCG09], game theory is used for Dynamic Spectrum Access algorithm with cellular operators. Authors have defined a utility function, for the operators, considering user's bit rate, the blocking probability and the spectrum price. Moreover, they have presented a penalty function to control the blocking probability.

In cognitive radio networks [EMCA13], where mobile users may switch in real time to the provider (or providers) offering the best tradeoffs in terms of QoS and paid price, Nash equilibrium concept is used to find the optimal price in a Stackelberg game between primary and secondary operators and Wardrop equilibrium is determined for the network selection game. Authors reveal the advantage for the primary operator to play before the secondary operator, particularly in a high-traffic regime.

Furthermore, a two-stage multi-leader-follower game is used to model the interaction of a number of wireless providers and a group of atomic users in [GHR14]. The providers announce the wireless resource prices in a first stage and the users announce their demand for the resource in the second stage. The user's choice is based on provider's prices and its channel conditions. Authors showed that the provider competition leads to a unique socially optimal resource allocation for a broad class of utility functions and a generic

channel model.

In this thesis, chapter 4, we modeled the interaction between wireless operators, in a multi-operator sharing network, as a multi-leader-follower (Stackelberg) game. Cooperating service operators announce their transaction cost in the first stage and the home operator of the transferred user performs the selection decision in the second stage. The game solution is found using Nash equilibrium concept, and the best response is determine for every pairs of leaders [FCS+15].

Another approach for Joint Radio Resource Management (JRRM) is introduced in [GAPRS07, GAPRS08]. Authors extended their single operator approach to a cooperation scenario between operators. They proposed a two-layer JRRM strategy to fully exploit the available radio resource and to improve operator revenue. The proposed economic-driven JRRM is based on fuzzy neural methodology with different classes of input parameters: technical inputs, economic inputs and operator policies.

Furthermore, a comparison between different access selection techniques was made in [WK13], it shows the strong and weak points of each techniques. We resume the comparison results in Table 2.3. We can point out on the implementation simplicity of MADM and its high precision, in addition to the high precision of game theory and its ability to fulfill an equilibrium between multiple entities. This made game theory the first choice to use in a sharing networks, where the partners seeks to selfishly maximize their gains.

Table 2.3: Comparison of Network Selection Techniques

	Utility theory	**MADM**	**Fuzzy logic**	**Game theory**	**Markov chain**
Objective	Utility evaluation	Combination of multiple attributes	Imprecision handling	Equilibrium between multiple entries	Consecutive decisions/rank aggregation/ priority evaluation
Decision speed	Fast	Fast	Fast	Middle	Middle
Implementation complexity	Simple	Simple	Simple	Complex	Middle
Precision	Middle	High	Middle	High	High
Decentralized	Yes	Yes	Yes	Yes	Yes
Traffic-oriented	No	No	No	Yes	No

2.4 Service Pricing in a Multi-Operator Network

In multi-operator networks, the mainstream models suggested in litterature consider a pricing game between radio access network operators [NH08, ZZ13, ZHN14, ZBDH14, BKA+15, BKA+13, AKB+15, FPK+12]. Commonly, the mobile user is a player of the game, his strategy is to select the best access that maximizes his own utility. The latter is a function of the available QoS and the access price. It is assumed that the user has to

pay for his new access, and the access price is decided dynamically by the operators or service providers, in order to maximize their payoffs. In this case, a competitive pricing scheme using hierarchical Stackelberg game is adopted.

In [ZBDH14], authors propose a multi-leader multi-follower Stackelberg game between Wi-Fi, small cell service providers (SCSP), macrocell service providers (MSP) and mobile users. Wi-Fi, SCSP and MSP are considered as the leaders of the game, and has to decide their service prices. The mobile users are the followers and based on the price of all the leaders, they selects a mixed strategy and chooses each leader with some probability. The utility of a leader represents its revenue, and the utility of the follower is the spectrum efficiency of an access minus the price to be paid. In addition, when a user is served by SCSP, he has to pay a second price for the MSP as an interference penalty price. The best price to adopt is found using Stackelberg equilibrium notion, by solving a multi-objective two-levels optimization problem.

In a similar oligopoly market, studied in [ZZ13], a number of wireless Access Points (APs), controlled by different Service Providers (SPs), compete for the service of large number of end users. The SPs as leaders set prices for APs first; and the end users as followers decide whether to accept the services and if they do, further decide which access point to select. In fact, users must pay before use. Authors define a disutility of accessing an AP which is the sum of the price set by this AP and the congestion function. The user would access the APs with least disutility. In the adopted system model, the number of end users is assumed large and the impact of a single user on the whole system is negligible, thus authors used Wardrop principle to find the equilibrium distribution of user demand flows on all APs. Besides, the payoff of a leader is defined as the Profits of an AP/SP, and the oligopoly equilibrium for the access price is achieved at the Stackelberg equilibrium point, that maximizes the SP individual profits given the flow distribution of the end users. The SP profit-maximizing problem is solved analytically when there only exist two APs, and when there are more APs the problem turns to be complex and intractable. In this work, there is no explicit cooperation cost interchanged between SPs, and the end users are considered homogeneous for all APs.

Although, in [ZHN14], the cooperation between MSP and SCSPs is studied, the small cell networks (SCNs) are assumed to operate in a hybrid access mode. Authors address the radio resource sharing and the service price that a MSP pays to SCSP, in addition to the service selection performed by the users. The behavior of users is qualified as dynamic and time-varying with the performance satisfaction level and cost. Thus, the need of MSP and SCSP to dynamically adjust the price and the open access ratio (resource sharing ratio), in order to match the time-varying demand of the users. For this objective, authors used a hierarchical dynamic game framework based on differentiel game theory and evolutionary game theory, in order to capture the dynamic behavior of SP and users. At the low level, the dynamic service selection is formulated as an evolutionary game, and the solution is found using Evolutionary Stable Strategy (ESS), the user makes the

service selection decision according to the access price and received throughput. In the upper level, the MSP and SCSPs sequentially determine the optimal pricing strategy and the open access ratio, using a Stackelberg differential game. The MSP as leader offers a service price to SCSPs in order to affect their open access ratio. The SCSPs, the followers control the open access ratio to maximize their own payoffs. The solution of the game is found using open-loop Stackelberg equilibrium. In the proposed framework, the user pays a fixed access price and receive a time-vatying throughput affected by the open access ratio, and the cooperation fees are paid by the MSP as a unit price for shared bandwidth.

A similar rewarding framework is proposed in [SPTC15], author uses a two-stages sequential game between MSP and femtocell owners. A reward is offered by the MSP to the femtocell owners in order to affect the spectrum sharing ratio. This reward is a share of the revenue from hybrid users payment. These users are players at the second stage of the game, they perform service selection decision between Macro or Femto-service. The advantage of these framworks is that a user is out of the pricing game and a fixed price is kept for his access. Such framwork can be adapted in a multi-operator environment, where we assume that the user always pays the access/service price set by his home operator. And when a transaction is performed, the home operator of the considered user pays a transaction cost to the new service operator. The latter sets its transaction cost and may control the portion of their shared resources, in order to maximize its profits.

Another approach excludes the users from the service pricing game. They are characterized by their demand and its probability distribution. The operators/service providers compete in order to maximize their profit in an oligopoly market. [NH08] represents two competitive pricing models for WiMAX and WiFi-based heterogeneous wireless network. The interaction between SPs was modeled using non-cooperative game models. Authors considered the case where SPs decide their price in a simultaneous-play, in this case, the solution is given by the Nash equilibrium. And, the case where WiMAX SPs are the leader and offer their prices before WiFi in a leader-follower game, in this case the solution in given by the Stackelberg equilibrium.

A two-stage multi-leader multi-follower game, called data offloading game is introduced in [GIHT13]. It models the interactions between BSs and APs in a free market as a two-stage non-cooperative game. In the first stage, every BS proposes the price that it is willing to pay to each AP for offloading its traffic. In the second stage, every AP indicates the traffic volume its is willing to offload for every BS. BSs are considered as the leaders of the game and APs are the followers. Authors showed that under the Nash equilibrium, every AP accepts only the BSs proposing the highest price, this price results from equalizing the maximum marginal cost reduction of all BSs and the marginal payment to the AP. In the proposed model, authors focused on the cost reduction of BSs and the profit improvement of the AP achieved from data offloading. The BS operator proposes the price as a reward for offloading the BS traffic.

In other models, the BS operator charges other operators with some payment rate for

serving a portion of their demand. This payment can be fixed before the cooperation game or could be decided when interacting. Such model of base station sharing is presented in [LMK14], where authors built a simple microeconomic model that examines the behavior of base station operators who are collocated in a single cell. Authors used a game theoretic formulation, where BS operators interact to decide about turning on or off each BS in order to maximize the global utility. The latter is the summation of all operators utilities taking into account the demand distributions for each customer, their energy costs, revenue from a served customer, loss of revenue from dissatisfied customers, service capacity and payment rate.

In [BKA+15], a roaming-based infrastructure sharing scheme is proposed. The switching off decision process is modeled using a static non-cooperative game played by N MNOs in M peripheral cells. Authors consider that part of the BS infrastructure in the M surrounding cells may be switched off during low traffic conditions, motivating MNOs to share the resources of the remaining active BSs in the same cell. The switching off algorithm aims at minimizing the individual MNO cost in a distributed manner. Authors defined a cost function that explicitly considers the roaming and operational costs for MNOs. Such that, when the traffic of a switched BS is roamed to an active BS, the MNOs of deactivated BSs pay a roaming cost to the active operators. The latters must consider additional cost for serving the roamed traffic, and the roaming cost is considered as a portion of the total operational cost. The selection of the BS for traffic roaming is made randomly with equal probability.

Our challenge is to design a framework for resource sharing and transaction cost pricing that involves access selection in a multi-operator environment, in order to guarantee operators and users satisfaction in the same time. None of the above sharing schemes proposes a solution on this issue.

2.5 Conclusion

In this chapter, we represented RAN sharing as a promising solution to upgrade mobile operators networks, in order to expand coverage, increase capacity, support higher data rates and enhance QoS in terms, with energy and cost efficiency. In fact, Active RAN sharing will reduce the time and the cost of deploying new mobile technology. Besides, we made a review of the main RAT selection methods, and classified them into mono-operator access network and multi-operator access network selection decision. In a shared RAN, access selection decision for multi-operator networks is needed, and the majority of works adopt game theoratical approaches to model the interaction between the different operators. Moreover, we outlined the principal approaches for inter-operators service pricing in a multi-operators/service providers environment. This service price can be a share of the user payment or a fixed price. In addition, it may be determined by the cooperating service provider or may be a reward from the home operator of the user

to this service provider. Including, we represented different models, where the user is a player and has to pay the cooperation fees, and other models where the user pays a fixed price and its the home operator pay these fees. In the following chapter, we introduce a new hybrid decision method for the access selection in a multi-operator environment, that maximizes jointly the operators and users satisfaction.

Chapter 3

Nearest Performance and Best Profit Access Selection Algorithm

In a multi-operator network, a number of operators deploying co-located base stations share their radio access in order to guarantee the service availability for end users. In such shared RAN, a user can be served through the network of his home operator or the network of another service operator in the sharing system. Consequently, when there is more than one available service operator, a selection decision must be made to associate the user to the suitable one. This chapter introduces our selection decision algorithm, NP-BPA. Based on a cost function, our algorithm considers jointly the offered QoS of the available service operator and the transaction profit, resulting from the end user transfer. Then, the performance of the proposed selection algorithm is investigated in different contexts with different numbers of partners. In addition, a performance comparison is made with MADM methods, precisely SAW and NPH, in a three operator environment. Further, an analysis of two coefficients of the cost function reveals the ability of an operator to express its strategy and to control the access selection decision of its user.

3.1 Selection Decision Parameters

We consider a system formed by a number of operators who decided to cooperate and share their RAN in order to ensure end users satisfaction and improve their revenues. We assume that the adopted selection algorithm is identical for all operators in the system and it is maintained and processed in a suitable unit guaranteeing a correct decision. A Coordinated Radio Resource Management (CRRM) is expected to be applied and a third trusty party is integrated in order to maintain and guarantee the inter-operators agreements especially for the transaction cost pricing. The user transfer to a new service operator, denoted by *S-op*, is triggred and controlled by its home operator, denoted by *H-op*. Therefore, when a user arrives in the system and his *H-op* cannot admit it neither ensure QoS requirements for his application, it is transfered to another cooperating

operator to avoid his rejection. The system logic is represented in Fig. 3.1.

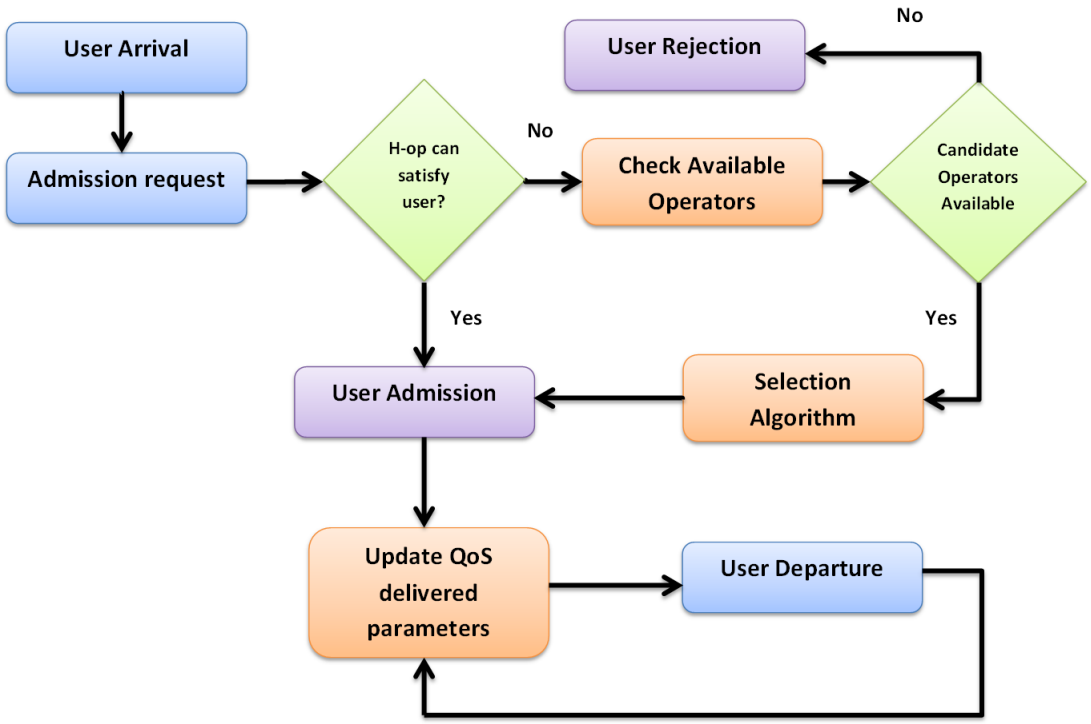


Figure 3.1: System Logic

The selection decision takes into account different parameters that could be collected from the user application requirements, the user profile and preferences, the available operators' access networks, the user handset, etc. The considered parameters differ with the context and the selection objectives, for exemple, when the selection decision seeks the user satisfaction in terms of QoS, parameters as the throughtput, delay, BER must be considered to satisfy the user application requirements.

In addition, when the user has limited budget for the service access, the service price of the new *S-op* has to be considered. Generally, the application requirements are specified based on QoS classes [KJ12b, SNW06]. We consider two classes: real time applications, which are sensitive to jitter and delay, and non-real time applications sensitive to the delay and the loss rate. The choice of two QoS classes helps to test the efficiency of the selection algorithm for associating the user to the suitable network. Besides, the user preferences are difficult to specify and depend strongly on the willingness of the user to pay. We can distinguish two sensitivity cases, in the first one the mobile user prefers to access the network of the *S-op* setting a service price close to his budget p, and in the second case the mobile user prefers to be connected to the *S-op* which delivers the closest QoS specifications to his application requirements independently of the service price.

Moreover, the access selection decision must consider the operator satisfaction, precisely the *H-op* of the transferred user. In fact, in our model the *H-op* has to pay the cooperation fees, *i.e*, the transaction cost Cs, to the service operator. Hence, the *H-op*

looks to maximize its own profits, and to apply its own strategy for the user transfer. We define the strategy of an operator as the determination to consider user satisfaction as a top priority to prevent any churn risk, or to ensure an acceptable QoS for its client while maximizing its profits. This strategy can be expressed explicitly in our cost function using two coefficients for the degree of importance of the user satisfaction and of the operator transaction profit. The latter is calculated at the transaction event, it is equal to the difference between the transferred user payment p and the transaction cost Cs to be paid for the *S-op,* considering the user demand.

Consequently, when a transaction event is triggered, the user application requirements, its preferences, the delived QoS parameters and Cs of the available *S-op* must be available, quantified and injected in a cost function. Each available *S-op* will be qualified by its cost function, then the selection decision is made. Figure 3.2 resumes the required parameters for the selection decision algorithm.

3.2 Decision Cost Function

For a "hybrid approach" that considers simultaneously the user and operator requirements, the selection problem must fulfill two objectives:

1. **User's Satisfaction**: We suppose that a user intends to connect to a single service. The admission request to his H-op contains information about the application type and his preferences as shown in Fig. 3.2. Once the H-op cannot meet the application requirements of its client, the request will be transferred to the cooperating operators. The selected operator must offer satisfaying QoS specifications. However, choosing always the operator with the best QoS specifications may penalize it by an overload and the others by under-utilization. Therefore, we suggest choosing the operator delivering enough QoS to fit user's application requirements. To achieve this selection, we exploit the NPH approach used in the context of multi-RAT under single operator [KJ12b]. The selected S-op must minimize the distance between the user application requirement and its delivered QoS parameters.

2. **Operator's Satisfaction**: When transfering its user, the H-op tries to maximize the transaction profit resulting from the user payment p and the Cs to be paid to the S-op. Consequently, the selection decision must fall on the partner maximizing $(p - Cs)$.

The selection candidates are the partners capable of fullfilling the user requirement, with the lowest cost. In the following subsections, we describe briefly the SAW scoring for the selection decision and the NPH approach in order to end to our selection cost function for the NP-BPA. Note, that in this chapter, we consider that the operators are sharing all their resources in a open access mode and do not make any reservation neither set a priority for their clients.

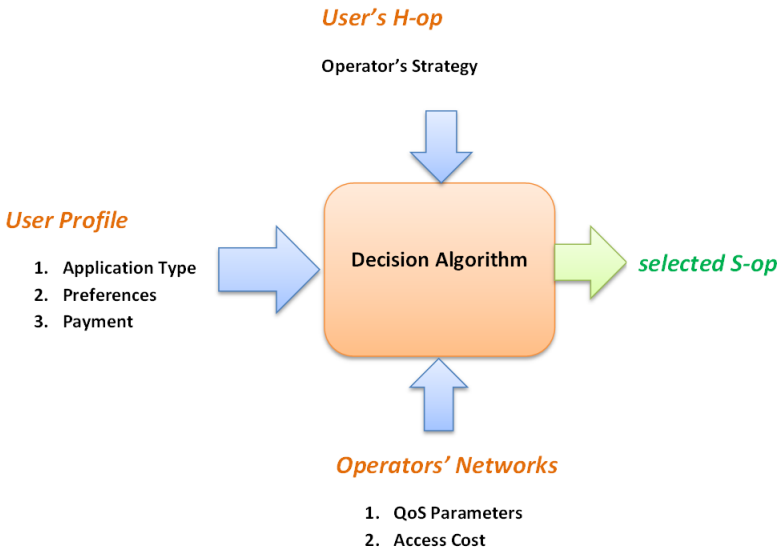


Figure 3.2: Decision parameters

3.2.1 Simple Additive Weighting (SAW)

With SAW, the parameters collected from each available access network, are normalized and combined with the corresponding sensitivity weights, then added to form the access network score [SNW06]. The access network having the highest score will be selected for the user service. In this work we consider four QoS parameters as in [KJ12b, SJ05]: the mean jitter J_M, the mean end-to-end delay D_M, the remaining bandwidth BW_M and the mean loss rate BER_M. In our multi-operator environment the access network is represented by its operator. Therefore, using the QoS parameters mentioned above, the score of the i^{th} service operator is calculated as follows:

$$S_i^{SAW} = w_J \cdot J_{M_i} + w_D \cdot D_{M_i} + w_{BW} \cdot BW_{R_i} + w_{BER} \cdot BER_{M_i} \tag{3.1}$$

where w_J, w_D, w_{BW}, and w_{BER} are the user application sensitivity weights for the jitter, the end-to-end delay, the bandwidth and the BER, respectively.

3.2.2 Hybrid Simple Additive Weighting (SAWp)

For a hybrid decision the satisfaction of the H-op must be taken into account during the selection. Thus, we propose to add to the previous SAW score the transaction profit $(p - Cs)$ in order to form SAWp score. Consequently, the score of the i^{th} service operator is calculated as follows:

$$\begin{aligned} S_i^{SAWp} = Wu \cdot (w_J \cdot J_{M_i} + w_D \cdot D_{M_i} + w_{BW} \cdot BW_{R_i} + w_{BER} \cdot BER_{M_i}) \\ + Wop \cdot (p - Cs_i) \end{aligned} \tag{3.2}$$

where Wu is the weight determining the degree of importance for the home operator to satisfy the user and Wop is the weight determining the degree of importance to improve

its profits. Finally, the operator having the highest SAWp score is selected for the user service. We developped this method in order to make a systematic comparison of the different selection decision approaches.

3.2.3 Nearest Performance Handover (NPH)

The NPH approach is initially proposed in a single operator context and can be used in our multi-operator environment, where each operator manages a single access network. It consists of defining the SAW score for the ideal solution, calculates the SAW score for every candidate, and then computes the distances of each candidate score to the ideal solution score. Finally, the access network with the closest score to the ideal one is selected for the service. The ideal solution score is the user's SAW score considering the QoS parameters required by the user's application. In order to adapt the NPH approach to our model, we propose to add the user budget p to its score, and the service price to the score to each service operator. Hence, the score of the user, Su, is computed as follows:

$$Su = \eta \cdot (w_J \cdot J_{req} + w_D \cdot D_{req} + w_{BW} \cdot BW_{req} + w_{BER} \cdot BER_{req}) + \theta \cdot p \tag{3.3}$$

where, J_{req}, D_{req}, BW_{req} and BER_{req} are the required jitter, delay, bandwidth and BER respectively, for user's application. These parameters are determined from the application QoS class, normalized and associated to their corresponding weights w_J, w_D, w_{BW} and w_{BER} , respectively. In addition, η and θ are the preference coefficients of the user for the QoS and the paid price, respectively. Symmetrically, the new score for the i$^{\text{th}}$ service operator, $S_i'^{SAW}$, is calculated as follows:

$$S_i'^{SAW} = \eta \cdot (w_J \cdot J_{M_i} + w_D \cdot D_{M_i} + w_{BW} \cdot BW_{R_i} + w_{BER} \cdot BER_{M_i}) + \theta \cdot p_i \tag{3.4}$$

where, p_i is the service price of the i$^{\text{th}}$ operator set for its clients. Finally, the score of the i$^{\text{th}}$ service operator is calculated as follows:

$$S_i^{NPH} = |S_u - S_i'^{SAW}| \tag{3.5}$$

Consequently, the operator delivering enough QoS parameters for user's application requirements, thus having the lowest S_i^{NPH} is selected for the service.

3.2.4 Nearest Performance and Best Profit Access Selection Algorithm (NP-BPA)

In our proposed algorithm, we consider the H-op happiness during the selection decision, thus, we combine the transaction profit of the H-op to S_i^{NPH} score in order to form a cost

function for the user transaction. Hence, the NP-BPA score of the i$^{\text{th}}$operator, S_i^{NP-BPA} is calculated as follows:

$$S_i^{NP-BPA} = Wu \cdot |S_u - S_i'^{SAW}| - Wop \cdot (p - Cs_i) \tag{3.6}$$

The selected operator offering the nearest performance parameters to the user requirements, thus having the closest score to Su, and setting the lowest transaction cost Cs_i, thus guaranteeing the best profit for the home operator is the selected one for service. Therefore, the selected operator is the one having the lowest S_i^{NP-BPA}.

3.3 Performance Analysis

The performance evaluation of our selection algorithm NP-BPA consists of showing the network performance enhancement in terms of blocking rates and the improvement of the global achieved profits, after cooperation. We go further inside results to show how the end users was exchanged, which partner is acting more as a service operator and why.

We start our analysis with an environment of two operators with different cases of shared capacity, than we increase the number of the cooperating operators to three and then to four in order to show how the number of sharing operator affects the degree of network enhancement and global profit improvement. For illustration, we adopt the system model presented in Fig. 3.3 where each operator manages a single radio access network.

We model the arrival and departure of users as a Poisson Process with mean arrival interval $1/\lambda\, sec$. Once connected, the user will stay in the system for a service time, assumed to follow an exponential distribution of mean $1/\mu$; we consider a typical value of $1/\mu = 4\, min$ [SJ05] . At the end of the connection, the user will leave the system thus, improving the available bandwidth of the serving operator. The simulation is implemented in MATLAB for a duration of 1200 sec, and the results are given with a confidence interval of 90%. After they arrive, mobile users are uniformly associated with a user profile, determining the service type, user preferences and the price to pay to his H-op. We consider two possible service types: real-time and non-real-time, the QoS weights corresponding to the bandwidth, the jitter, the delay and the loss rate are determined by applying AHP [SJ05, SNW06], and are given by the following vectors: [0.05, 0.45, 0.45, 0.05] and [0.16, 0.04, 0.16, 0.64], respectively.

The normalization of the different parameters is done for each operator's access network with respect to the user service requirements. For, the user preferences represented by the coefficients η and θ in equation 3.3 , we use two vectors: [0.4 0.6] in the case where the user is more sensitive to price, and [0.9 0.1] in the case where the user is sensitive to QoS [Saa80].

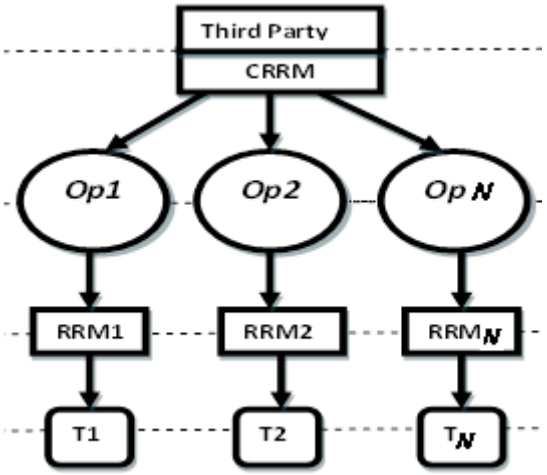


Figure 3.3: System Model

We consider a set of three operators, and the QoS parameters delivered by each operator are presented in Table 3.1. These parameters are adopted for the performance study in this chapter. The service price set by each partner will be specified for each sharing system and the transaction cost for each partner is set equal to its service price.

We start our study by a two operator system to show the benefits of cooperation and how it depends on the sharing partner. Then, we investigate the efficiency of our selection algorithm, NP-BPA, in a three operator system. Finaly, we show that our results persist in a four operator system.

Table 3.1: Operators' Delivered Parameters

Operator i	**Bandwidth (kbps)**	**Jitter (ms)**	**End-to-End Delay (ms)**	**BER**
Op_1	1700	6	19	10^{-3}
Op_2	11000	10	30	10^{-5}
Op_3	5500	12	45	10^{-5}

3.3.1 Partner Slection in a Two operator System

In this subsection, we consider two partners in the system. In such environment, there is no need for a selection algorithm, thus the performance analysis aims to show in the first place the benefits of cooperation between two operators, and to answer the question "who to share with?"; the choice of the sharing partner, and the consequences of cooperating with an operator sharing more or less capacity. We start by considering an operator as Op_3, that intends to cooperate with another operator presented in Table 3.1. We distinguish three cases depending on the shared capacity of the chosen partner. In the first case, denoted by *CEC*, for Equal Capacity, the partner of Op_3 shares an equal capacity and it is denoted by Op_3x. In the second case, denoted by *CLC,* for Less Capacity, Op_3 chooses to cooperate with Op_1 sharing the lowest capacity. And, in the third case, denoted by *CHC,* for Higher Capacity, Op_3 chooses Op_2that shares the highest

capacity. For comparison, we use the values $1/\lambda = 3.33$, 4, 5, 7, 9, 12, 24 sec for the mean inter-arrival interval, and $p_1 = p_2 = p_3 = 0.2\, unit/kbytes$ for the service price, in order to follow the effect of the capacity independently of the service price, in all cases CEC, CLC and CHC. Further, in each case we consider the NonCooperation state where the operators acts independently and no sharing is considered.

3.3.1.1 CEC case:

Considering the two operator system with no capacity or QoS differentiation, formed by Op_3 and Op_3x, we show the benefits of sharing on the blocking rates and the partners global profits .

Global blocking rates Global blocking rates calculated as the ratio of the total number of rejected and arrived users, in the system. Figure 3.4 shows the blocking rates of system formed by Op_3 and Op_3x in function of the arrival rates, with and without cooperation between the partners. Results show that sharing could reduce the global blocking rates by especially at high arrival rates, where cooperation is a need. Note that, the improvement of the blocking rates increase with the arrival rates showing the benefits of sharing to prevent the system overload.

Operators' blocking rates: Figure 3.5 shows the blocking rates of Op_3 and Op_3x networks, respectively, in function of the arrival rates. It is clear that the network performance of both operators are very close and they improve it in the same way, since they share the same capacity. It is expected that when cooperating with an operator sharing better capacity, Op_3 can improve better its blocking rates, this will be investigated in the third case CHC.

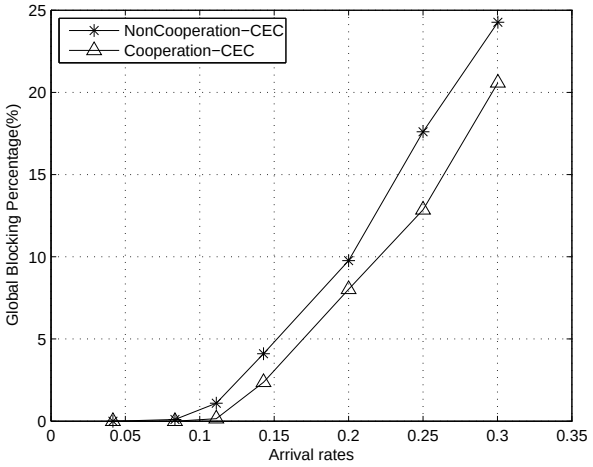


Figure 3.4: Global blocking rates-CEC case

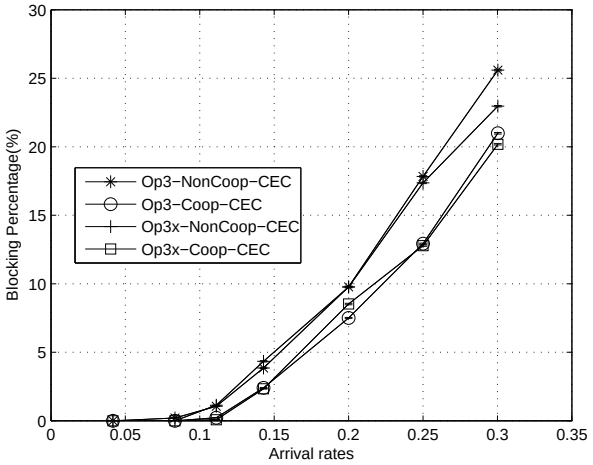


Figure 3.5: Op3's and Op3x's blocking rates-CEC case

Operators' global profits: Figures 3.6 and 3.7 show the global achieved profit for Op_3 and Op_3x, respectively, in function of the arrival rates. This profit is calculated as the total income from clients and guest users minus the transaction cost paid for users transfer. Both partners are improving profit through cooperation, and are achieving similar values. Since, Op_3 and Op_3x set the same service price, thus the same Cs. Considering the confidence interval of the profit values, we can say that both partner are taking the same advantages from sharing and improve their profits in the same way. It is important to examine the rate at which Op_3 and Op_3x acted as a S-op for the users of the partner. Table 3.8 shows the service rates of guest users for both $Op_3$and Op_3x. Percentages show that each operator serves the same amount of guests coming from the second partner.

We can conlude that when partners share the same capacity and offer the similar QoS with simlar service price, they grab the same benefits from cooperation.

Table 3.2: Serving rates of guest users-CEC

Serving rates (%)							
Arrival rates	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7
Op_3	0	0	1	4	11	13	15
Op_3x	0	0.1	1	5	10	12	14

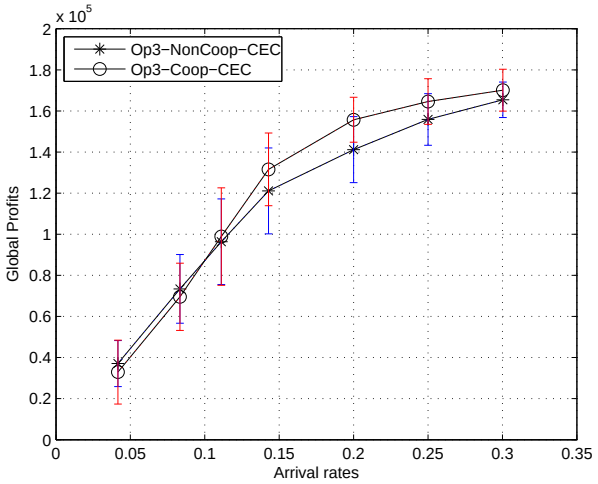


Figure 3.6: Op3's global profits-CEC case

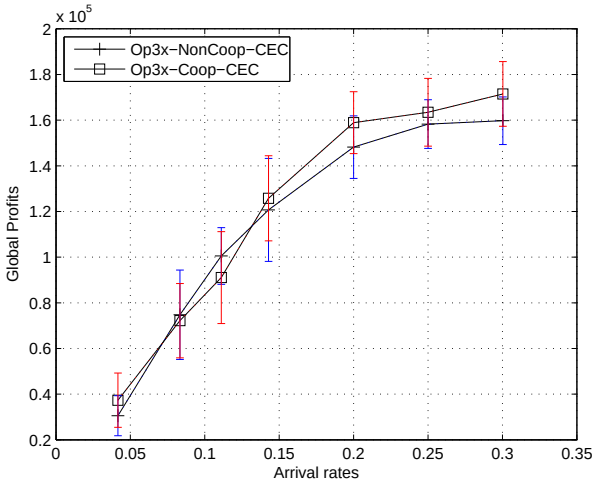


Figure 3.7: Op3x's global profits-CEC case

3.3.1.2 CLC case:

In this part of the analysis we are interested to show what happens when Op_3 cooperates with a partner sharing lower capacity. It is important to show the effects on the network performance of the considered operators and their profits. In addition, we are concerned about which partner will benefit most of the sharing agreement in this case. Therefore, we consider the system formed by Op_3 and Op_1.

Global blocking rates: Figure 3.8 shows the global blocking rates of the system formed by Op_3 and Op_1, with and without cooperation . With cooperation, the global

blocking rates of the system are reduced by 31%. These rates are reduced to 0% at low arrival rates, but they increase with the arrival rates to reach higher level than in the CEC case Fig. 3.4. The limited capacity of Op_1 is causing a lot of user rejection in the system.

Operators' blocking rates: Figures 3.9 and 3.10 show the blocking rates for Op_1 and Op_3 , respectively, with and without cooperation. Results show a very important reduction of the blocking rates of Op_1's network. This operator could face overload situations through cooperation. But, it is dramatic for Op_3, its network blocking rates increases with cooperation. In fact, Op_3 is serving high number of guest users coming from Op_1 which affect extremly its user acceptance. This is one drawback of sharing with a limited capacity operator, especially when sharing all the capacity. It may be a good solution to make a sort of resource reservation for the clients (own subscribers) to prevent this effect. Resource reservation will be highlighted in Chapter 5.

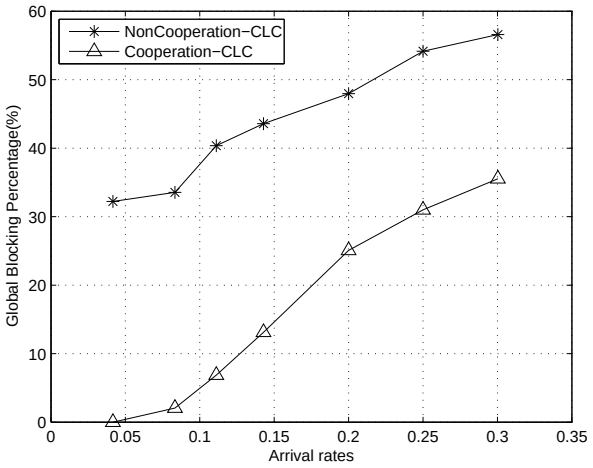


Figure 3.8: Global blocking rates-CLC case

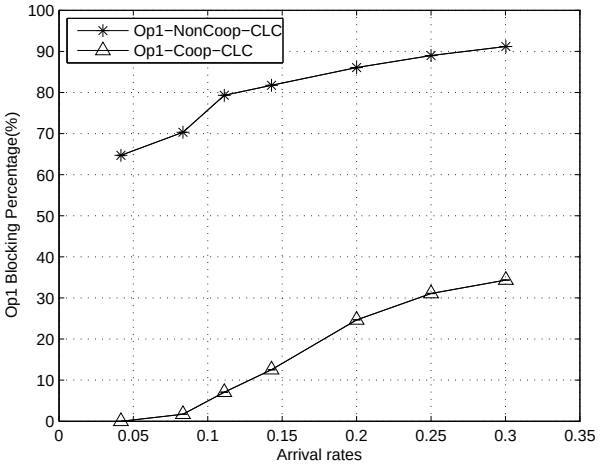


Figure 3.9: Op1's network blocking rates-CLC case

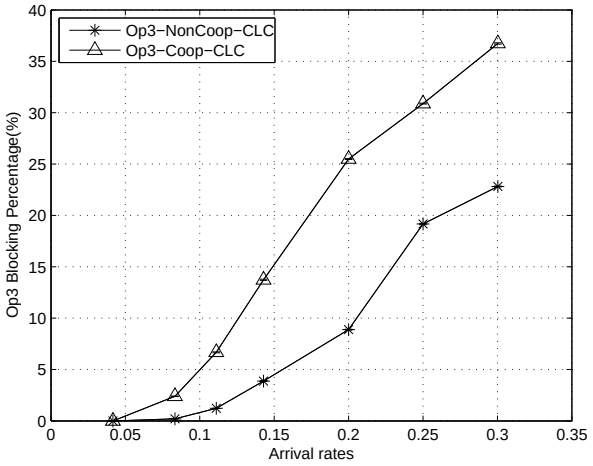


Figure 3.10: Op3's network blocking rates-CLC case

Operators' global profits: Figures 3.11 and 3.12 show the achieved global profits for Op_1 and Op_3, respectively, with and without cooperation. Op_1 is performing a lot of transactions in order to improve user acceptance, which causes a lot of costs preventing profit improvement even if it is getting additional incomes from a modest number of guest users. Op_3 , serving high number of guest users, is achieving important profit improvement thanks to the additional incomes from guests. The service rates of guest users, in Table 3.3, show that Op_3 is acting more than Op_1 as a S-op, in addition these rates are higher than in CEC case when $Op3$ was sharing with a comparable operator.

We can conlude that when an operator cooperates with a limited capacity partner, it may degrade its client acceptance especially when it adopts an open access mode. But, profit gains are always guaanteed.

Table 3.3: Serving rates of guest users-CLC

Serving rates (%)							
Arrival rates	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7
Op_1	0	2	6	10.5	23	28	26
Op_3	39	42	43	46.5	47	48	30

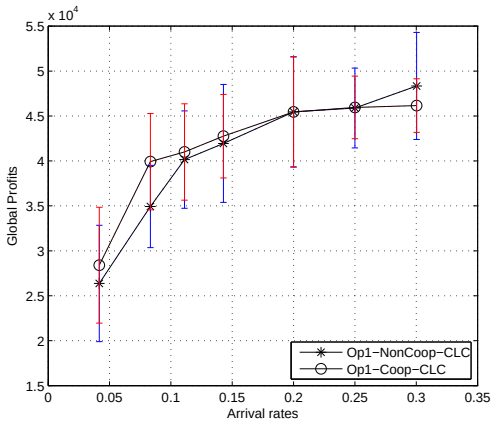


Figure 3.11: Op1's global profits-CLC case

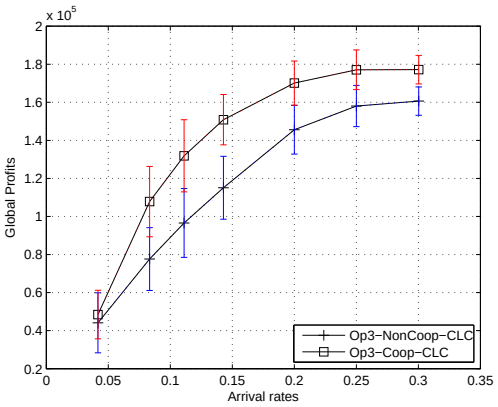


Figure 3.12: Op3's global profits-CLC case

3.3.1.3 CHC case:

From previous results in the *CLC* case, we can predict that when sharing with an operator with higher capacity, as Op_2, Op_3 will improve the global performance of the system and will decrease the blocking rates of $Op3$'s network. The results for $Op3$ will be similar to those for Op_1 in the *CLC* case. It is interesting to see if the profits of $Op3$ will decrease from the values achieved in the *CLC* case.

Global blocking rates: Figure 3.13 shows the global blocking rates of the system formed by Op_2 and Op_3. With cooperation these operators could reduce the global blocking rates of the system by 45% at high arrival rates and limit it below 7 %. These rates are reduced to 0% at low arrival rates. The cooperation with Op_2 induced higher improvements than with CEC and CLC cases, as shown in figures 3.4 and 3.8, respectively.

Operators' blocking rates: Figures 3.14 and 3.15 show the blocking rates for Op_2 and Op_3 , respectively, with and without cooperation. Results show a very important reduction of the blocking rates of Op_3's network, around 76%. This operator could improve well the user acceptance through cooperation, and in this case Op_3 achieved lower levels of blocking than with CEC and CLC. But, again Op_2, with better capacity, was penalized and its user acceptance decreased with cooperation, however, it still in an acceptable range at high arrival rates.

Operators' global profits: Figures 3.16 and 3.17 show the achieved global profits for Op_2 and Op_3, respectively, with and without cooperation. Comparing the results with those of Fig. 3.12, in CLC case, the profits of Op_3 are lower in CHC case, and no important improvement is noticed. In fact, the increase of Op_3's user acceptance is achieved through a high number of transactions, which causes a lot of costs. And, additional incomes are very modest from guest users. Therefore, Op_3 could not recover the profit reduction. For $Op2$, the profit gains arise at high arrival rates where it begins to serve guest users coming from Op_3.

We can conclude that sharing with another operator brings benefits for at least the network performance in terms of blocking rates or the achieved profits, the degree of improvement of the blocking rates depends on the difference between the shared capacities of the partners, and the profit gain arise when the operator acts more as a S-op. In this situation, the S-op must consider resource reservation, instead of the open access mode, in order to prevent overload states caused by guest users.

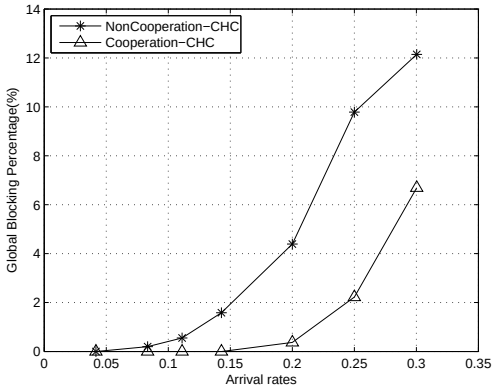


Figure 3.13: Global blocking rates-CHC case

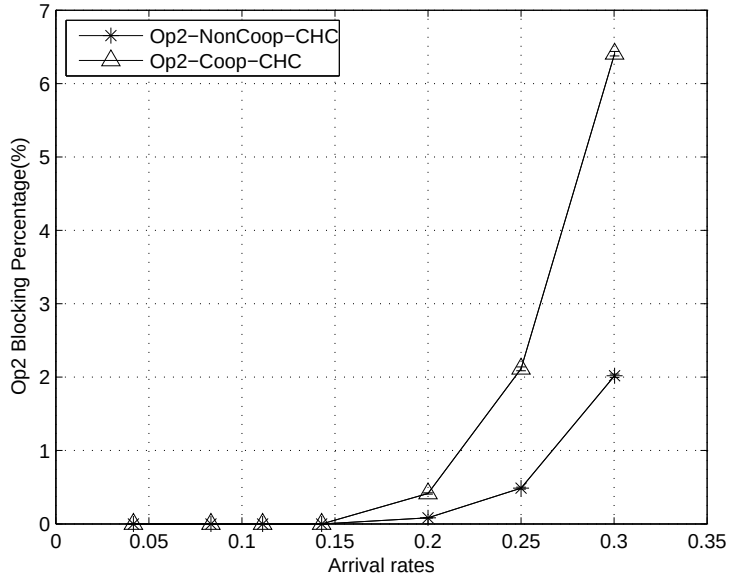


Figure 3.14: Op2's network blocking rates-CHC case

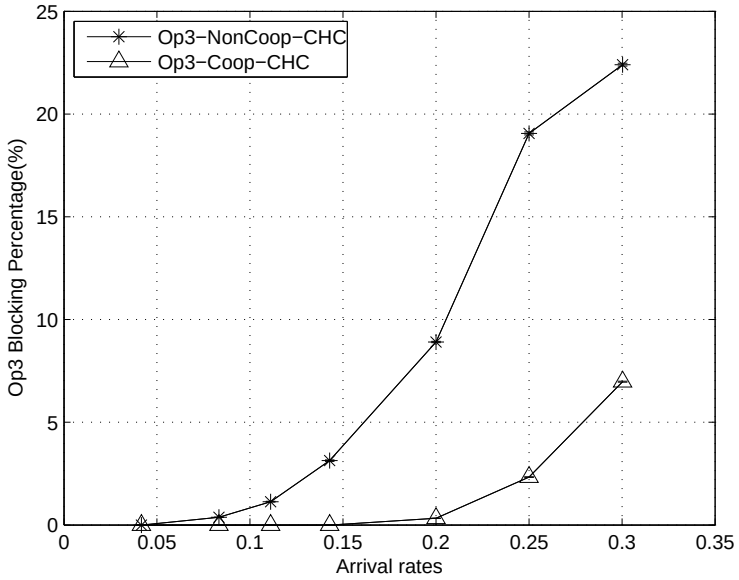


Figure 3.15: Op3's network blocking rates-CHC case

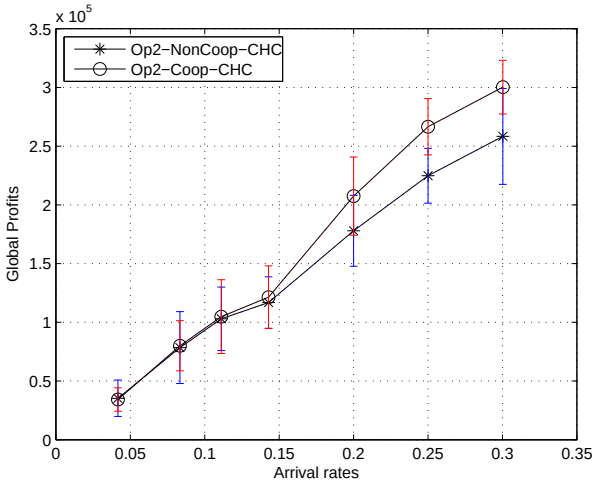


Figure 3.16: Op2's global profits-CHC case

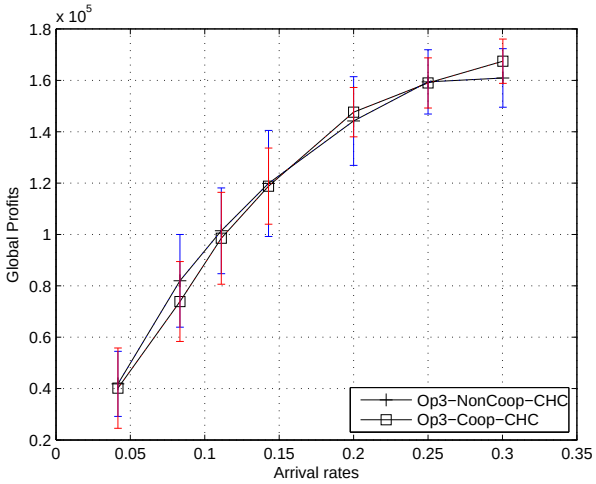


Figure 3.17: Op3's global profits-CHC case

3.3.2 Access Selection in a Three Operator System

In this subsection, we consider the sharing system formed by the three operators Op_1, Op_2 and Op_3, denoted by *Sys3*, and we implement our selection algorithm, NP-BPA. Without loss of generality, we simulate our scenario using the specifications given in Table 3.1. For the service price p, we use the following values: $p_1 = 0.9$, $p_2 = 0.1$ and $p_3 = 0.2$ $unit/kbytes$, for Op_1, Op_2 and Op_3, respectively. As we mentioned before in section 3.3, we consider two types of applications: real time and non-real time which require the QoS parameters depicted in table 3.4 and used in [SJ05]. In addition, we use the values $1/\lambda = 2.7, 3, 3.33, 4, 5, 7, 9, 12, 24\, sec$ for the mean inter-arrival interval.

Table 3.4: User's Application Requirements

Application type	**Jitter (ms)**	**End-to-End Delay (ms)**	**BER**
Real Time	10	100	10^{-3}
NonReal Time	20	150	10^{-5}

The performance analysis in terms of blocking rates and profits improvement is made for a value of $^{Wu}/_{Wop} = 1$ in equation 3.6. A further study will be presented in this chapter for the effect of the ratio $^{Wu}/_{Wop}$ on the selection decision and how to chose its suitable value. In addition, the transaction cost of each operator i is set equal to its service price p for all partners such that $Cs_i = p_i$. Consequently, a client will pay p_i for his H-op Op_i and the latter will pay $Cs_j = p_j$ for the S-op Op_j. The transaction cost Cs pricing is studied in the next chapter. The following results are presented within a confidence interval of 95%.

3.3.2.1 Global performance:

As in the case of two partners, the global performance of the system is studied in terms of global blocking rates. Figure 3.18 presents the global blocking rates of the system in function of the arrival rates λ. It shows an excellent reduction in the blocking rates, about 95%, when the three operators cooperate. These rates are maintained below 0.5% at low and medium arrival rates.

3.3.2.2 Network performance:

Figures 3.19a, 3.19b and 3.19c show a comparison between the blocking rates, with and without cooperation, for Op_1, Op_2 and Op_3, respectively. On one hand, Op_1, sharing a limited capacity, is taking the largest benefit from this cooperation. Its blocking probability is reduced up to 78% (Fig. 3.19a). Op_1 could face overload situations by transferring its clients to Op_2 and Op_3. On the other hand, our selection algorithm, NP-BPA, allowed the partners acting as S-op in a higher rates to maintain their users acceptance. Op_3 has limited its blocking percentage below 1% after cooperation (Fig. 3.19c), and Op_2 could maintain the blocking percentatge below 0.3% at high arrival rates. Op_2 has benefitted slightly of this cooperation (Fig. 3.19b); this operator already had a low blocking rate even without cooperation.

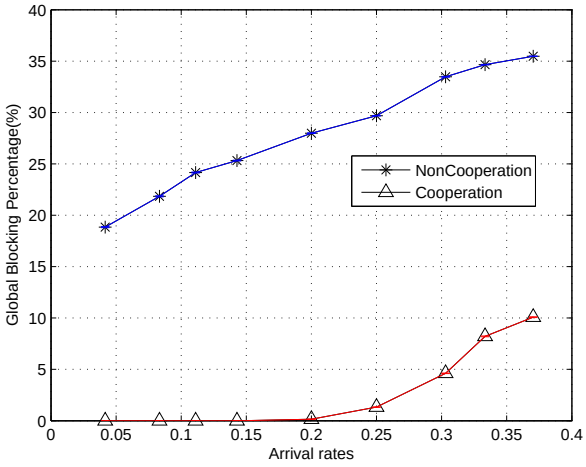
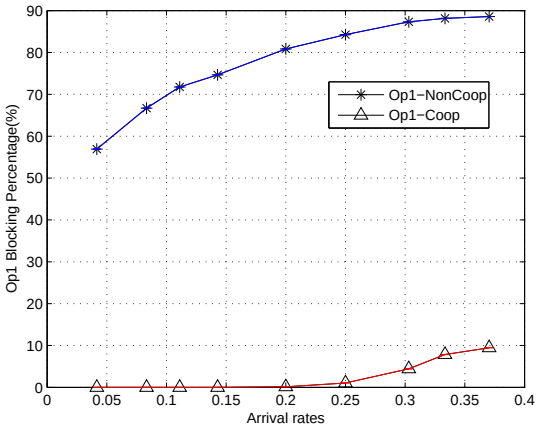
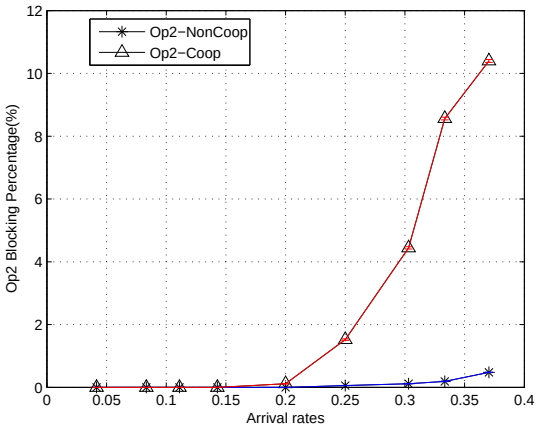


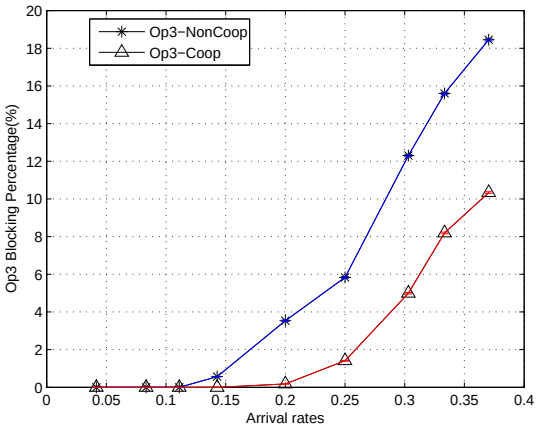
Figure 3.18: Global blocking rates in *Sys3*



(a) Op_1's blocking rates in *Sys3*



(b) Op_2's blocking rates in *Sys3*



(c) Op_3's blocking rates in *Sys3*

Figure 3.19: Operators' network blocking rates in *Sys3*

3.3.2.3 Operators' profit improvement:

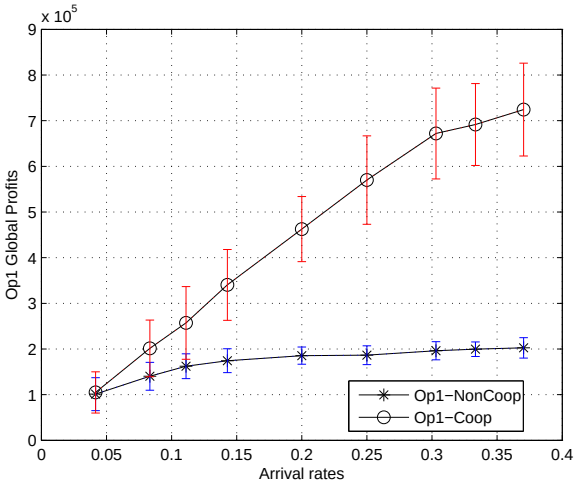
Figures 3.20a, 3.20b and 3.20c show the global achieved profits in function of the arrival rates, for Op_1, Op_2 and Op_3 , respectively. Comparing the achieved values with cooperation and those without cooperation, one can see that the operators of the sharing system could realize important profit gains through cooperation. Our selection algorithm could guarantee the satisfaction of the operators transfering their users by selecting the S-op with lower costs.

We can conclude that the important increase of the users' acceptance after cooperation, brought more incomes for Op_1; clients are transferred to another serving operators instead of being blocked and loosing their payments Fig. 3.20a. Op_3 also benefits from profit improvement, Fig. 3.20c. Extra incomes have risen after cooperation, because of the increase of users' acceptance and the service of guest users. For Op_2, profit gains are achieved, although the increase of the rejection at high arrival rates. In fact, high rate of guest user are served at high arrival rates insuring additional incomes. A further study of the serving rates of Op_2 (percentage of served guest users from total served users) in table 3.5, has revealed that more than 35 % of the served users are guest users. This did not affect the profits of Op_2 because of the adopted pricing scenario (its transaction cost is equal to its service price), but the effect was clear on the client acceptance rate.

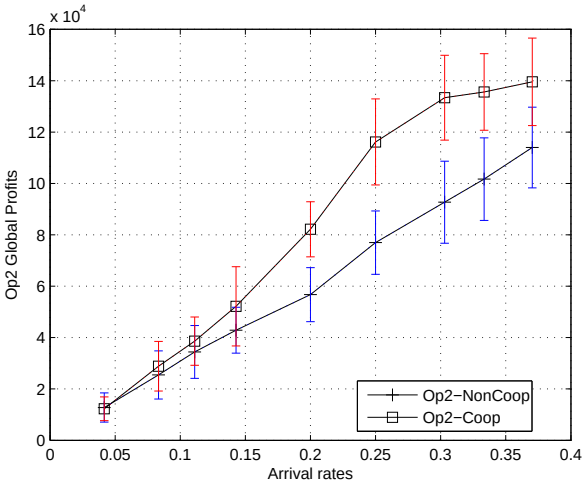
We can conclude that important benefits in terms of blocking rates and achieved global profits are achievable through cooperation. In addition, the number of partners in a sharing system affects the amount of improvement in the blocking rates and profits. From previous results, we can hightight the effect of the shared capacity and the transaction cost on the cooperation profitability. In fact, in *Sys3*, if Op_2 sets a transaction cost higher than the service prices of Op_1 and Op_3, the latters will suffer from profit loss at high arrival rates. At these rates, Op_1 and Op_3 perform high rates of transactions in order to improve client acceptance. Besides, the fact that Op_2 is sharing all its capacity with other partners affected negatively the client acceptance, since no priority is set and no reservation is done for own subscribers, thus guest users were more lucky to be served.

Table 3.5: Op2's Serving rates (%) in *Sys3*

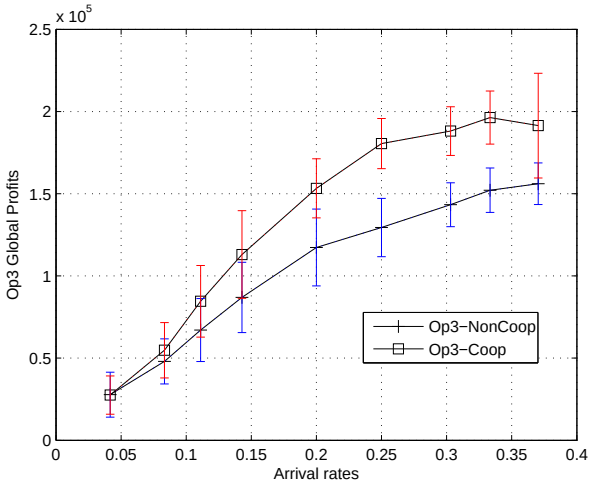
Serving rates (%)									
Arrival rates	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7	λ_8	λ_9
Guest percentages	35	35	35	37	43	45	48	48	50



(a) Op_1's global profits in *Sys3*



(b) Op_2's global profits in *Sys3*



(c) Op_3's global profits in *Sys3*

Figure 3.20: Operators' Global Achieved Profits in *Sys3*

3.3.3 Access Selection in a Four Operator System

In this subsection, we show that cooperation benefits still achievable in a four operators sharing system and we highlight the efficiency of our selection algorithm in such sharing system. We add a new partner Op_4 to the previous system *Sys3* (presented in subsection 3.3.2), and we assume that this operator offers the same parameters as Op_3 (see table 3.1). The new four operators system is denoted by *Sys4*. For simulation, we use the same values of the mean interarrival rates and the mean service rate as in the previous subsection 3.3.2.

Figures 3.21, 3.22 and 3.23 show the global blocking rates, the networks blocking rates and operators' global profits in *Sys4* with and without cooperation. The analysis of the new results show the same conlusions concerning the benefits of the cooperation in a three operators sharing system. We can resume these conclusions for Sys4 as follows:

1. Improvement of the global blocking rates in *Sys4* from 14 to 23%, at high and low arrival rates , respectively, showed in Fig. 3.21.

2. Improvement of the network blocking rates for the sharing partners having low to moderate capacity as Op_1, Op_3 and Op_4 showed in figures 3.22a, 3.22c and 3.22d, respectively.

3. Penalization of the partner sharing the highest capacity because of the high serving rate (rate of acting as a service operator for guest users) as for Op_2 in Fig. 3.22b.

4. Improvement of the global profits for all *Sys4* 's partners through cooperation, as showed in Fig.s 3.23a, 3.23b, 3.23c and 3.23d for Op_1, Op_2, Op_3 and Op_4, respectively.

In addition, the observation of the network performance and the global profits of the partners sharing the same capacity and setting the same service price, shows very close behavior for the blocking rates improvement and profit gains. Hence, the partners offering the same parameters for sharing will achieve the same benefits from cooperation.

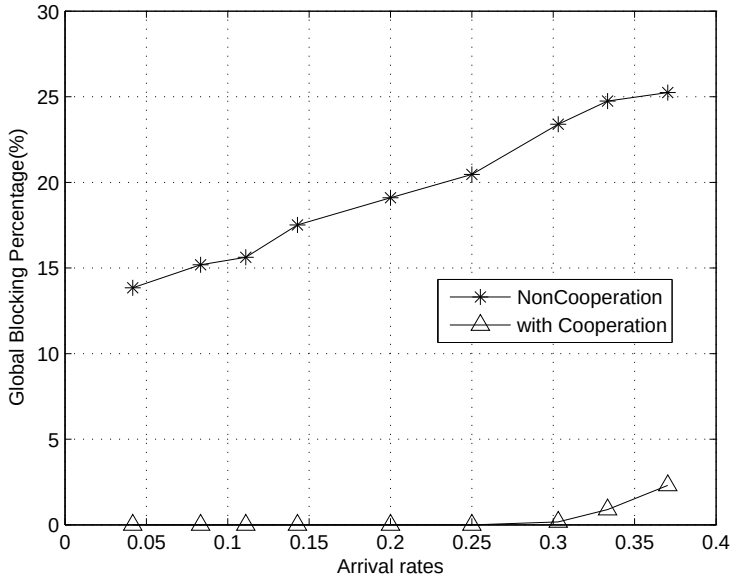
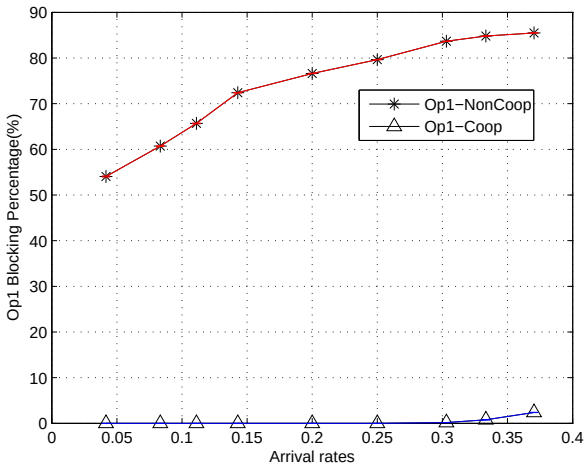
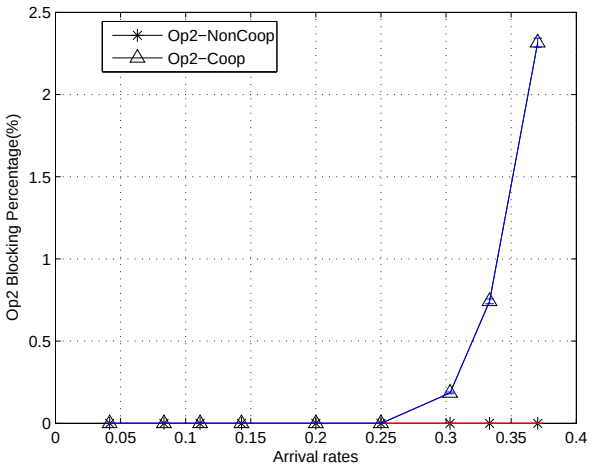


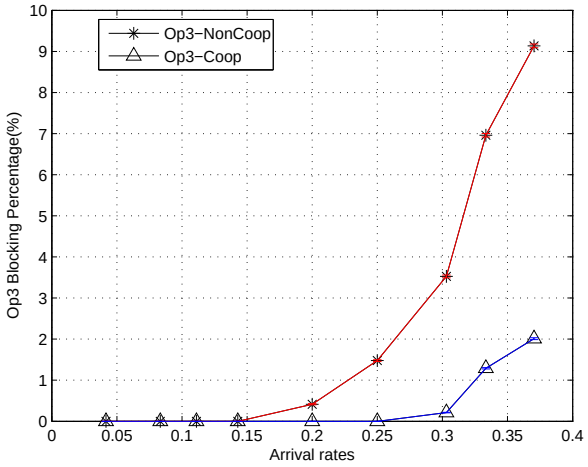
Figure 3.21: Global blocking rates in *Sys4*



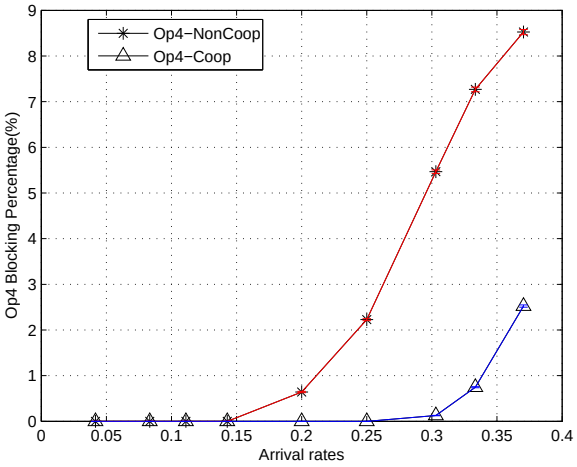
(a) Op_1's bloking rates in *Sys4*



(b) Op_2's bloking rates in *Sys4*

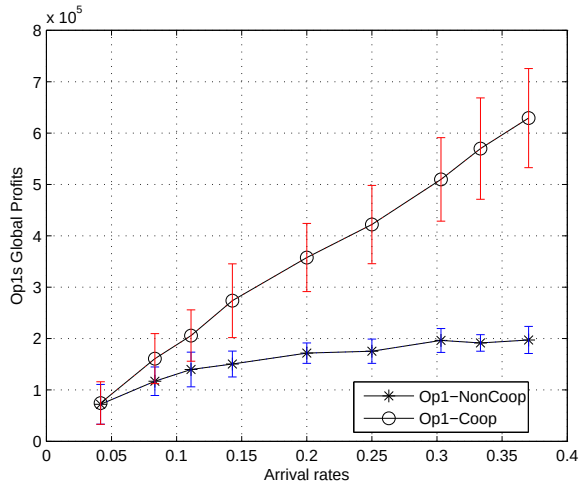


(c) Op_3's bloking rates in *Sys4*

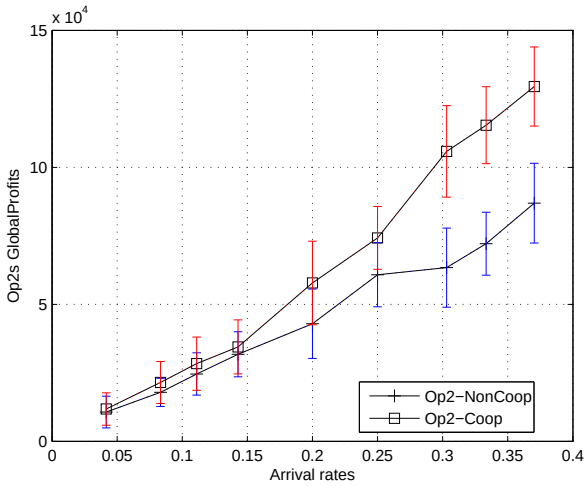


(d) Op_4's bloking rates in *Sys4*

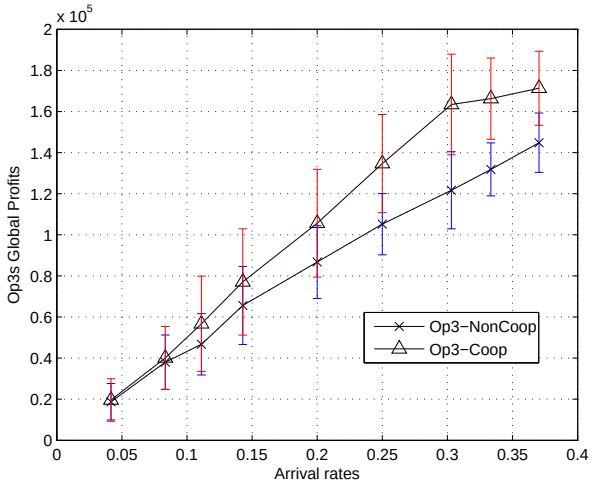
Figure 3.22: Operators's Networks blocking rates in *Sys4*



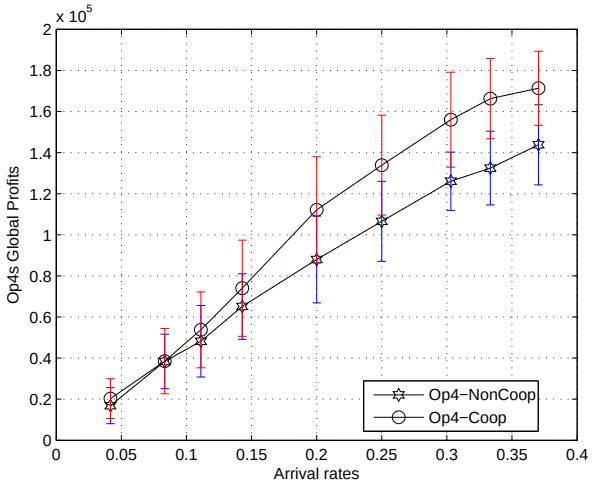
(a) Op_1's Global profits in *Sys4*



(b) Op_2's Global profits in *Sys4*



(c) Op_3's Global profits in *Sys4*



(d) Op_4's Global profits in *Sys4*

Figure 3.23: Operators' Global Profits

3.4 Performance Comparison with MADM methods

Our approach for the conception of a selection algorithm in a multi-operator environment was initially inspired by SAW for its simplicity. Moreover, the NPH algorithm helped us to envisage a solution that prevents overloading the operator delivering best QoS specifications, in the sharing system. In this section, we make a comparison between our slection algorithm, NPH and SAW and SAWp methods described in the subsections 3.2.4, 3.2.3, 3.2.2 and 3.2.1, respectively. We use the system model and simulation setup detailed in section 3.3, and we consider *SyS3* formed by Op_1, Op_2 and Op_3.

Table 3.6: Comparison of the selection percentages of the service operators(%)

	NP-BPA			**SAW**			**SAWp**			**NPH**		
	Op_1	Op_2	Op_3	Op_1	Op_2	Op_3	Op_1	Op_2	Op_3	Op_1	Op_2	Op_3
Op_1	-	99.5	0.5	-	100	0	-	100	0	-	0	100
Op_2	0	-	100	0	-	0	0	-	0	0	-	0
Op_3	0	100	-	100	0	-	100	0	-	100	0	-

3.4.1 Global blocking rates

Figure 3.24 shows the results for the global blocking rates of *Sys3* in function of the arrival rates. Each curve represents the blocking percentages achieved using one of the investigated selection algorithm, NP-BPA, SAW, SAWp and NPH. These blocking percentages increase with the arrival rate. With NPH, blocking percentages increase fast and achieve very high values. These percentages are lower with SAW and SAWp but they reach 18 % at high arrival rates. With NP-BPA, global blocking percentages are limited between 0 and 1%. Our decision algorithm reduced extremely the global blocking percentages, it prevent overloading service operators with limited to moderate capacities . Table 3.6 presents the selection results for all arrival rates, it shows the percentage of users transferred from one operator to another adopting different selection algorithm. It is clear that with NPH all transferred users are served by Op_1 or Op_3 having limited and moderate capacity, respectively. However, with SAW and SAWp, the transferred users are served by $Op2$ and Op_1 with high and limited capacities, respectively. And, with NP-BPA the selected service operators are Op_2 and Op_3 with high and moderate capacities, respectively.

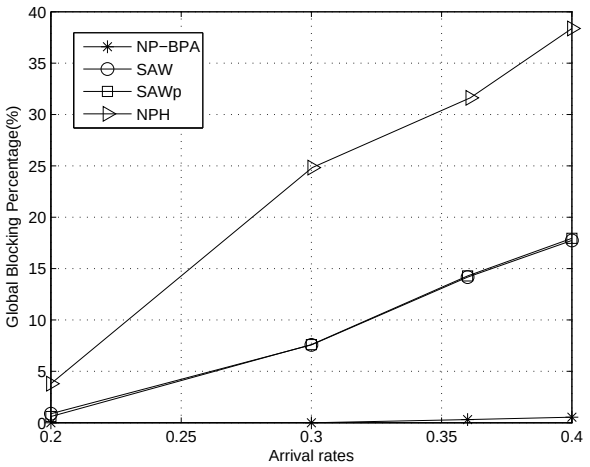


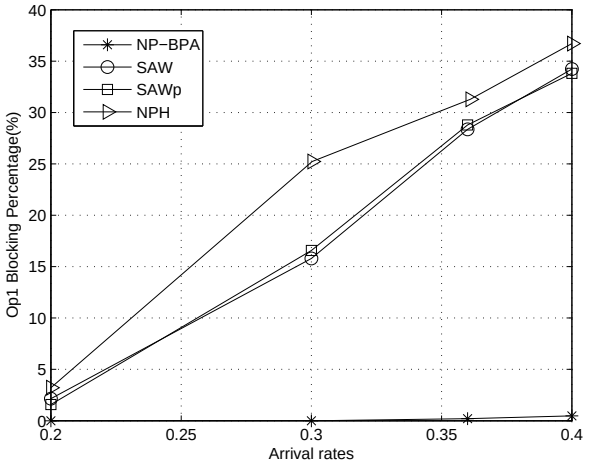
Figure 3.24: Comparison of the global blocking rates

3.4.2 Operators' Network Performance

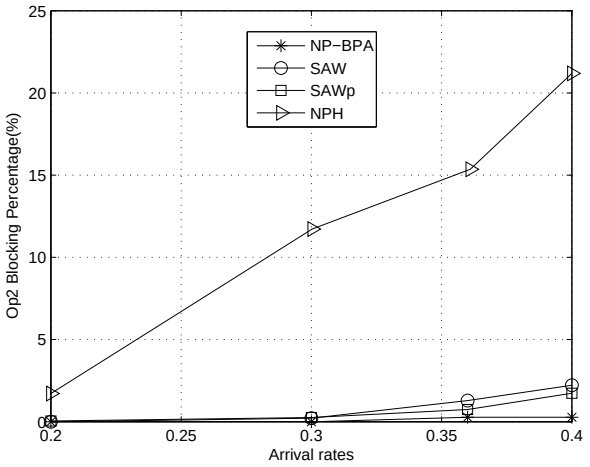
Figures 3.25a, 3.25b and 3.25c show the blocking rates in function of the arrival rates, for Op_1, Op_2 and Op_3, respectively, using NP-BPA, SAW, SAWp and NPH. Simulation results show that, for all operators, our proposed cost function NP-BPA guarantee the lowest blocking rates, for all arrival rates. SAW and SAWp present the same performance, the achieved blocking rates are very close and are low for Op_2 which has already a high capacity. SAW and SAWp represent the same performance as NP-BPA for the operator having the highest capacity. However, for Op_1 and Op_2 the performance of SAW and SAWp degrades and high blocking rates are achieved using these algorithms, they reach 34% for Op_1 and 16% for Op_3. NPH presents the worst performance; blocking rates increase fast and they reach very high values 36% for Op_1, 21% for Op_2 and 35% for Op_3. Hence, NP-BPA proves the efficiency of load balancing between service operators, in order to prevent overloading situation and affect user acceptance.

3.4.3 Global Achieved Profits

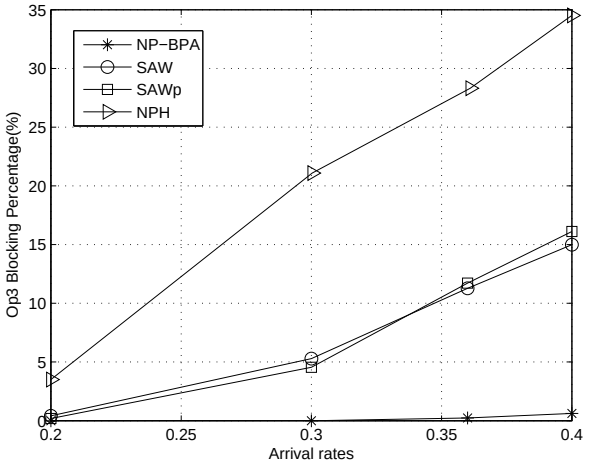
Figures 3.26a, 3.26b and 3.26c show the global achieved profit for Op_1, Op_2 and Op_3, respectively, using NP-BPA, SAW, SAWp and NPH. The global profit of an operator depends on the amount of income from serving clients, revenue from transferred clients, revenue from served guest users coming from another operator and the amount of transaction cost charged when transferring clients. With NP-BPA, Op_1 and Op_3 achieve the highest profits which increase with the arrival rate. Op_2 maximizes its profits using NPH and NP-BPA comes in the second place. Although, with NPH, Op_2's profit degrades at high arrival rates, and is monotonic with NP-BPA, SAW and SAWp. In fact, with NP-BPA, Op_1 reduced a lot the client rejection, thus, more revenues are available from added clients and from transferred ones. In addition, NP-BPA guarantees the selection of the service operator with the lowest Cs, which reduces the total Cs paid when transferring clients. Figures 3.27a, 3.27b and 3.27c show the total incomes and cost for Op_1 using NP-BPA, NPH and SAW, respectively. One can see that with NP-BPA more clients are served and the paid transaction cost Cs is minimized. It is the same case with Op_3, as show figures *3.29a, 3.29b* and *3.29c*. For Op_2, the achieved profits using NPH overcome the profits using other methods. However, NPH did not improve user rejection, and profit gains are from the high number of guest users that were transferred to Op2 as shows Fig. 3.28b. Although, at high arrival rates, profits degrade with NPH, Op_2 is unable to transfer its users to another service operator because lack of resource, nether serve new guest users. Consequently, the profits decrease. Notice that SAW and SAWp have a very close performance concerning the global achieved profits of all operators, and when they differ, SAWp achieves higher profits than SAW, which is clear for Op_3. These methods guarantee more profits than NPH, for Op_3, because more clients are served without being penalized by guest user service, as shows Fig. 3.29c.



(a) Comparison of Op_1's blocking rates

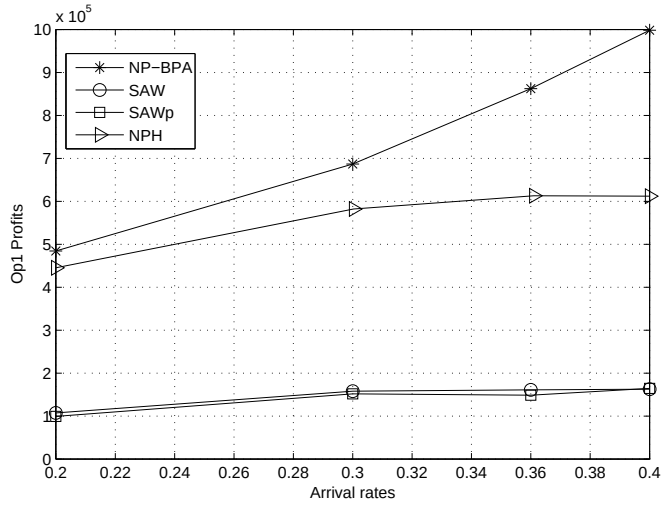


(b) Comparison of Op_2's blocking rates

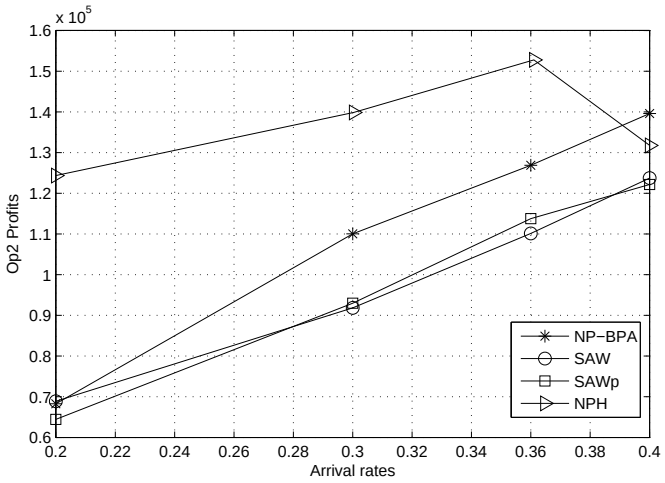


(c) Comparison of Op_3's blocking rates

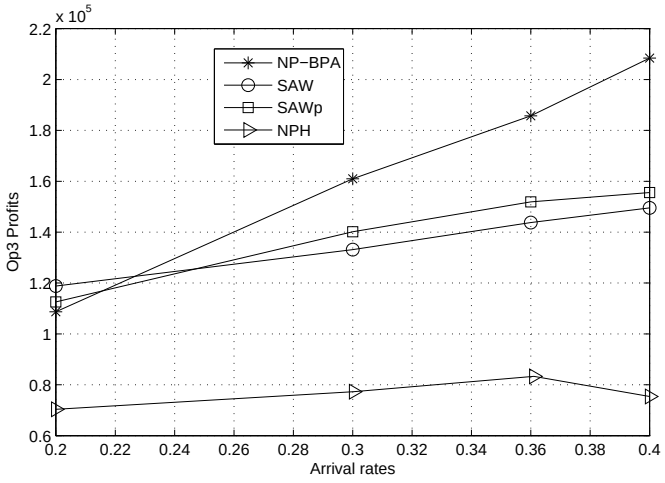
Figure 3.25: Comparison of operators' networks blocking rates



(a) Comparison of Op_1's global profits

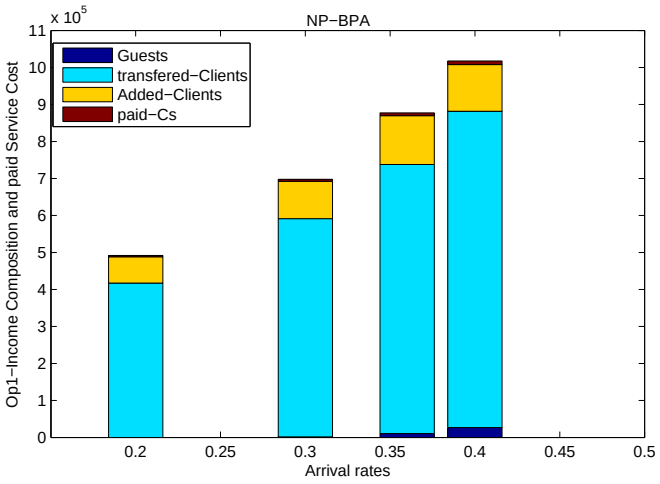


(b) Comparison of Op_2's global profits

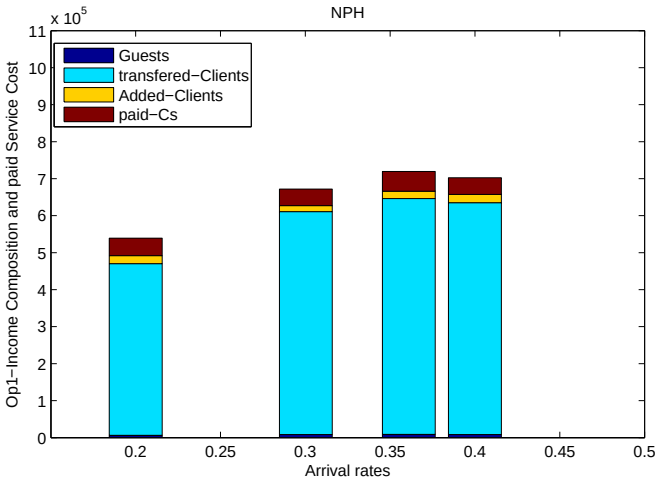


(c) Comparison of Op_3's global profits

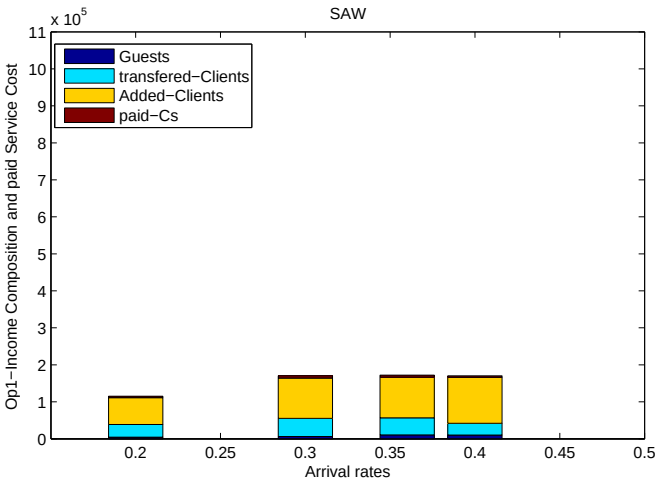
Figure 3.26: Comparison of operator's global profits



(a) Op_1's income decomposition and costs with NP-BPA

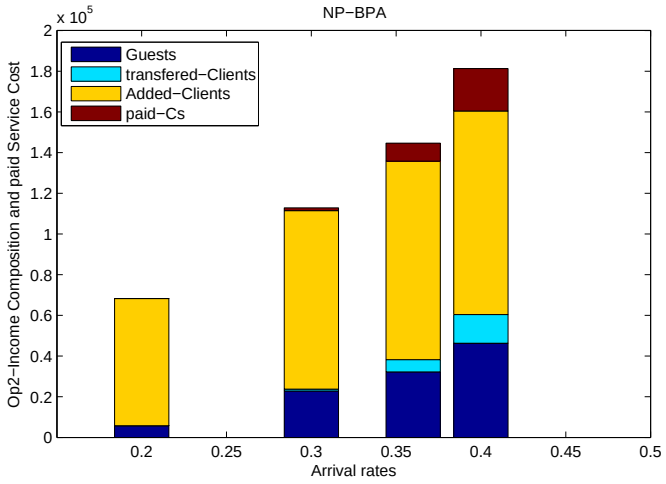


(b) Op_1's income decomposition and costs with NPH

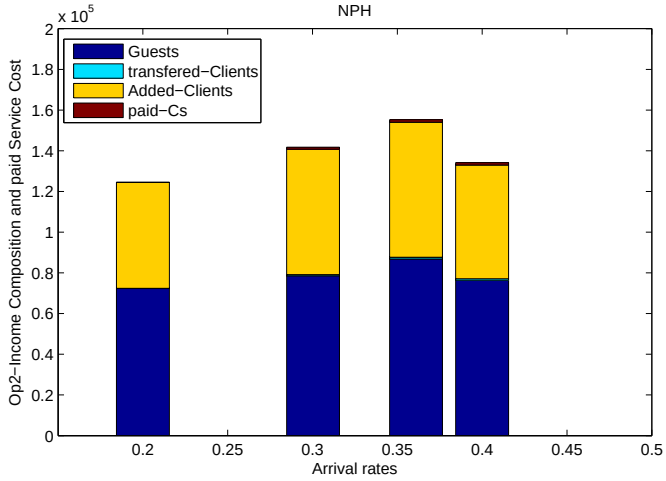


(c) Op_1's income decomposition and costs with SAW

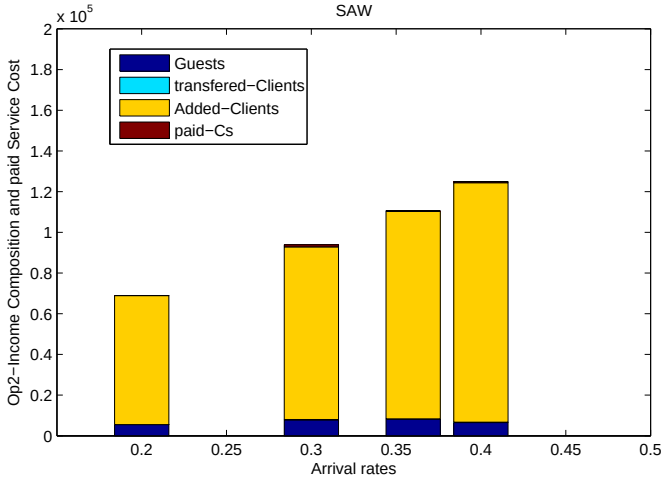
Figure 3.27: Comparison of Op_1's income decomposition and costs



(a) Op_2's income decomposition and costs with NP-BPA

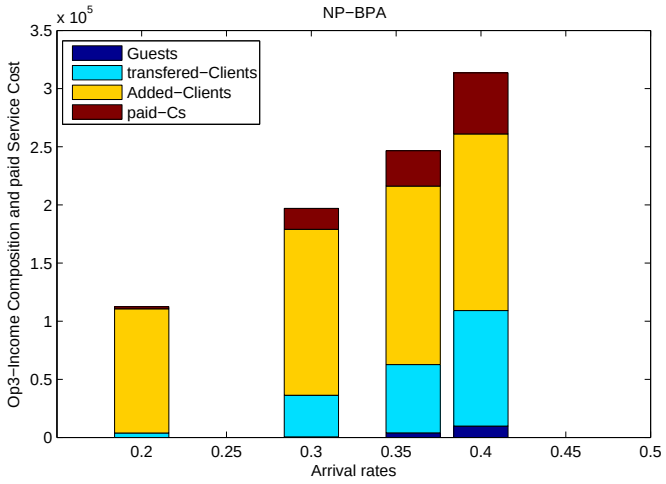


(b) Op_2's income decomposition and costs with NPH

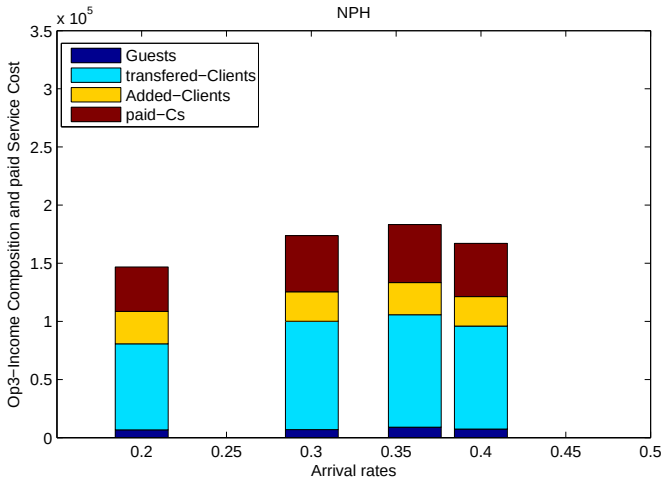


(c) Op_2's income decomposition and costs with SAW

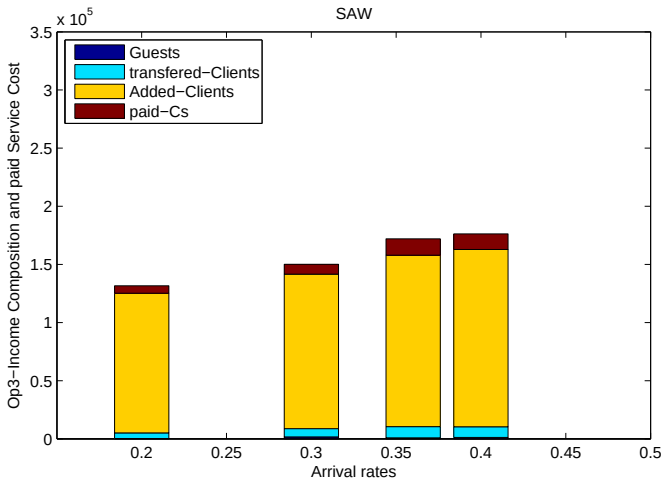
Figure 3.28: Comparison of Op_2's income decomposition and costs



(a) Op_3's income decomposition and costs with NP-BPA



(b) Op_3's income decomposition and costs with NPH



(c) Op_3's income decomposition and costs with SAW

Figure 3.29: Comparison of Op_3's income decomposition and costs

3.5 Access selection control

In our cost function made for the NP-BPA algorithm in equation 3.6, the coefficients Wu and Wop are considered as two weights determining the degree of importance for the home operator to satisfy the user and the degree of importance to improve its profits, respectively. In fact, the value of these weights affects the transaction direction and which service operator to be selected. Moreover, the ratio $^{Wu}/_{Wop}$ expresses the operator strategy to improve profits or to maximize its client satisfaction. With NP-BPA algorithm, we provide the H-op the ability to control the selection process with respect to its strategy, wherever this selection algorithm is implemented. By tuning the value of the ratio $^{Wu}/_{Wop}$, H-op will direct its client to the service operator satisfying its own strategy. In fact, this ratio is bounded by a limit L, which is function of the pricing scenario determining p and Cs and the distance $|S_u - S_i'^{SAW}|$ between the user requirements and the service operator delivered parameters, used in the cost function of the equation 3.6. The values of the ratio $^{Wu}/_{Wop}$, which are below the limit L, allow to select the operator maximizing the H-op profit, and the values above L permit to select the operator that satisfy the user's application requirements.

For illustration, let us consider our system with three operators, and assume that for the user transaction we have two candidates Op_m and Op_n. These candidates have $S_m'^{SAW}$ and $S_n'^{SAW}$ as SAW scores and set Cs_m and Cs_n for the service cost, thus having S_m^{NP-BPA} and S_n^{NP-BPA} , respectively:

$$\begin{cases} S_m^{NP-BPA} = Wu * |S_u - S_m'^{SAW}| - Wop * (p - Cs_m) \\ S_n^{NP-BPA} = Wu * |S_u - S_n'^{SAW}| - Wop * (p - Cs_n) \end{cases} \tag{3.7}$$

If the profits per transaction are higher when the user is served by Op_m, H-op can use suitable values for Wu and Wop to maintain $S_m'^{SAW} < S_n'^{SAW}$ and thus selects Op_m, in this case $^{Wu}/_{Wop}$ must fulfill the following condition, defining the limit L:

$$\frac{Wu}{Wop} < \frac{(p - Cs_m) - (p - Cs_n)}{|S_u - S_m'^{SAW}| - |S_u - S_n'^{SAW}|} = L \tag{3.8}$$

Wherever this algorithm is maintained, H-op will communicate its strategy for the selection, and the values of Wu and Wop will be chosen in order to respect it. Once the selection parameters are available for processing, the limit L is calculated using equation 3.8, and then Wu and Wop are chosen such that $^{Wu}/_{Wop}$ is below or above L depending on H-op's strategy. If H-op intends to choose the service operator with lower cost, $^{Wu}/_{Wop}$ must be chosen below L, else if he seeks the operator delivering the best parameters for its client, $^{Wu}/_{Wop}$ must be chosen above L. Further, in the case where there is more than two candidates for the selection as in a four partners system, the candidates are considered pairwise, in order to deduce the limit L_1 and L_2 for each pair. Finally, we adopt the inferior limit to tune the value of $^{Wu}/_{Wop}$.

For this study, we consider the same system model in Fig. 3.3 with three operators Op_1, Op_2 and Op_3. The delivered parameters are the same as in Table 3.1 and we use the service prices 0.9, 0.1 and 0.6 unit/KBytes for Op_1, Op_2 and Op_3, respectively. We follow the exchange process for mobile users seeking real-time service with high arrival rates. We are interested to specify for each operator acting as H-op, the S-op with minimum score distance to the user requirements, and the S-op generating the best profit for H-op. Based on Table 3.1 and the service prices, candidate operators are qualification in Table 3.7.

Table 3.7: Candidate operators qualification

H-op	**Candidate operator guaranteeing**	
	Best QoS parameters for the user	*Best profits for H-op*
Op_1	Op_3	Op_2
Op_2	Op_1	Op_1
$Op3$	Op_1	Op_2

Simulation results for the effect of the choice of $^{Wu}/_{Wop}$ on the selection are presented in Table 3.8. Selection results show that, a ratio below the limit L guarantee all the time that H-op selects the operator maximizing its profits, in other words; minimizing costs. In fact, in this scenario where $Cs_i = p_i \ \forall Op_i$, we can distinguish three cases:

1. The H-op must choose between two operators inducing different profits (case of Op_1): in this case, when $^{Wu}/_{Wop}$ is tuned below L, the best profit S-op is selected.

2. The H-op must choose between an operator with generating profits and another causing losses (case of Op_3): in this case a value below L guarantees the selection without losses.

3. The H-op must choose between two operators, each having high service costs and causes losses to the H-op (case of Op_2): in this case, when $^{Wu}/_{Wop}$ is lower than L, H-op selects the S-op causing him lower loss.

Table 3.8: Service Operator selection(%)

Selection Direction(%)							
$\frac{Wu}{Wop} > L$				$\frac{Wu}{Wop} < L$			
	Op_1	Op_2	Op_3		Op_1	Op_2	Op_3
Op_1	-	0	100	Op_1	-	100	0
Op_2	100	-	0	Op_2	100	-	0
$Op3$	100	0	-	$Op3$	0	100	-

3.6 Conclusion

In this chapter, our selection decision algorithm NP-BPA for the access selection in a multi-operator environment is introduced, this algorithm guarantee the user and its home operator satisfaction, simultaneously. The efficiency of this algorithm is shown in a sharing system formed by three and four partners. In addition, the performance of this algorithm is compared to MADM methods precisely SAW and NPH in a three operators system. NP-BPA showed better results for the blocking rates and global achieved profits. Through this chapter, we proved the benefits of cooperation between operators and how the choice of the partner affect the network performance improvement and the profit gains.

Moreover, when the number of partners increases, the benefits of sharing persist and the partners delivering the same parameters benefits the same from cooperation. Further, when a partner acts as a S-op in a high rate it risks of overloading its network with guest users, which affects its clients acceptance. One solution resides in choosing the suitable transaction cost able to induce additional incomes in the sharing system and control the guests flow. Another solution is to limit the shared resource with guests in a hybrid access mode. These solutions are studied in chapter 4 and 5, respectively.

Chapter 4

Inter-operators Transcation Cost Pricing

In order to achieve a successful network sharing, partners must agree on inter-operator pricing for ongoing services, how revenues are distributed and how operational, rental and power costs are shared. The sharing agreement must be maintained by a trusty party to keep up with different challenges that appear with sharing. In this chapter, the inter-operators service cost is studied. It is represented by the transaction cost paid by the home operator of a transferred user, to the new service operator. Three pricing scenarios are proposed in order to set the transaction cost of a service operator. Then, these scenarios are compared with other price sharing scenarios that consist of sharing the transferred user payment between its home operator and the service operator. Moreover, the study of the best pricing scenario to adopt in the system is achieved using game theory. The interaction between the operators of the sharing system is modeled using a Stackelberg game where the available service operators are the leaders and the home operator of a transferred user is a follower.

4.1 Introduction

The inter-operators agreement determines how an operator pays for its user transfer. In some models, this transaction fees can be a fixed payment made by the user's H-op to the S-op. It may be specified as a penality price as in [LMK14, ZBDH14]. In other models, this cooperation fees can be a portion of the user payment made to his H-op, this portion is related to the load of the new service operator or the churn rate of the H-op [GAPRS07, GAPRS08, SPTC15, CSP13]. In a roaming based sharing networks, the transaction fees are specified as a roaming cost and it is considered as a portion of the total operational cost of the new S-op base station as in [BKA$^+$13, BKA$^+$15, AKB$^+$15]. In our sharing system, the transaction cost is a function of the service prices set by the partners, the payment of the user goes to his H-op and the latter pays a transaction cost

Cs to the S-op. In fact, the transaction cost and the service price of the partners affect the access selection decision as shown in equation 3.6. Hence, we find logical to have a relation between Cs and the service price of one operator, on one hand, and between Cs of an operator and the service price of other partners, on another hand. Moreover, the service price p is a public information that an operator can share with other partners comparing to the operational cost, the load or the churn rate which is related to the blocking rates in the operator network [GAPRS08]. Besides, p is a quasi-static parameter, thus relating Cs to p reduces the rate of information exchange in the sharing system comparing to other parameters used in the literature.

We summarize the investigated parameters as follow:

- p_i: service price of an operator i paid by its clients (own subscribers).
- Cs_i: transaction cost of an operator i paid by the H-op of a guest user (user transferred from H-op to operator i).
- $\max_i(p_i)$: is the highest service price set in the sharing system (most expensive).
- $\min_i(p_i)$: is the lowest service price set in the sharing system (cheapest).

4.2 Proposed Pricing Scenarios

Motivated by the aforementioned characteristics of the service price p, we investigate three new pricing scenarios, where the transaction cost Cs_i set by an operator i is a function of its service price p_i or a function of the service price set by other partners in the sharing system. Therefore, an operator Op_i sets its transaction cost Cs_i, following three different functions of the service price p_i, corresponding to each pricing scenario. These scenarios, and the motivation behind as well as the performance evaluation for each of them are presented in the following:

A. Scenario I- denoted by **ACAG** (As Client As Guest): To prevent any loss of investment, a guest user must generate the same revenue as from a client user. Therefore, the transaction cost set by $S\text{-}op_i$ is equal to its service price p_i; $Cs_i = p_i$. In this scenario, we intend to track the following:

1. The profit improvement for the operator i in the system with cheap service price p_{i}.
2. The cooperation benefits for the operator i having the most expensive service price p_{i}, since Cs_{i} affects the access selection decision for a transferred user, see equation 3.6.

B. Scenario II- denoted by **MIWC** (Max In When Cooperating): We may notice that with scenario ACAG, an operator having the cheapest service price will pay a higher

price for its client transaction and gain less from guest users. It could face losses when client transaction is frequent. Thus, in this scenario, we propose that all the sharing partners sets a transaction cost equal to $Cs = \max_i(p_i)\ i = 1, 2, 3 \ldots$ In this scenario, it is guaranteed that all available S-op set the same cost. Hence, we intend to test if:

1. The cooperation still beneficial for operators even when it causes profit losses.
2. The operator having the cheapest price is improving his profit.

C. Scenario III-denoted by **MCWC** (Min Cost When Cooperating)**:** When an operator performs a high number of transactions, it will pay high costs with MIWC, since the operator pays the highest Cs. Partners may find better to pay less and get less than pay more. Thus, in this scenario we propose that all partners set a transaction cost equal to $Cs = \min_i(p_i)\, i = 1, 2, 3 \ldots$ The study of this scenario targets the possibility of achieving profit gain with a low service cost.

Furthermore, it is important to consider two instances of the financial agreement. The first one, when all the partners agree to adopt the same pricing scenario, such that all sharing operators adopt scenario ACAG or MIWC or MCWC, and the second one, when every operator of the sharing system decides its proper pricing scenario, among ACAG, MIWC and MCWC, in order to maximize its benefits.

4.3 Price sharing scenarios-pShareα

In addition to the above proposed scenarios, we consider several price sharing scenarios where the selected service provider gets a portion of the transferred user payment. In this case, the transferred user payment p_{i} assigned to H-op$_{\mathrm{i}}$ is shared as follows: H-op$_{\mathrm{i}}$ keeps $(1-\alpha)\, p_i$, $\alpha \geq 0$ and S-op takes αp_i. In this inter-operator pricing scenario, the transaction cost gained by a service operator is related to the service price of the H-op of the transferred user, and not to its own service price as in our proposed scenarios.

Depending on the value of α, different sub-scenarios can be envisaged, we consider three sub-scenarios:

1. pShare1: known as SOGAR (Service Operator Gets All Revenue) in [GAPRS07]: S-op gets all the income from the user transfer, with $\alpha = 1$.
2. pShareL: known as SRBL (Shared Revenue Based on Load) in [GAPRS07] and [GAPRS08]: $\alpha = \eta$, where $\eta \leq 1$ is the normalized load of the S-op, so that the new service operator gets higher income when it is more loaded.
3. pShare0: with $\alpha = 0$, i.e, no charges are depicted for user exchange, and H-op gets all client's payment. This scenario may not be real, but can be used in a symmetric system as in CEC case presented in subsection 3.3.1.1.

4.4 Pricing Scenarios Comparison

The aformentioned pricing scenarios are compared in two different system models for the performance analysis. In fact, the profitability of a pricing scenario depends on the service rate of an operator (how much it acts as a S-op) and the amount of incomes that guarantee this pricing scenario. Thus, two important elements are to be considered: the shared capacity and the the service price. Therefore, we define two system models made for simulation, **BSBC** (Best Scenario Based on shared Capacity) and **BSBP** (Best Scenario Based on service Price):

1. **BSBC** model: In this model, we assume that all operators deliver the same QoS specifications for the mobile users and set the same service price p, then we consider different shared capacity for each operator. Although, setting the same service price for all operators reduces the simulated scenarios to pShare scenarios and **ACAG** because $\min_i(p_i) = \max_i(p_i) = p$. In addition, **ACAG** is expected to generate identical benefits as generated by pShare1 in this model. Besides, since the candidates S-op offer the same transaction profits, this model allows to reveal the relation between the amout of shared capacity and the achieved profit with each pricing scenario and for each partner.

2. **BSBP** model: In this model, we assume that all operators deliver the same QoS specifications, share the same amount of capacity, but set different service prices p_i. Since the considered pricing scenarios are functions of the service price p_i of the operators, this model allows to examine the capability of an operator i to improve its profits even with a transaction cost Cs_i lower than its service price p_i.

4.4.1 Simulation Setup and Results

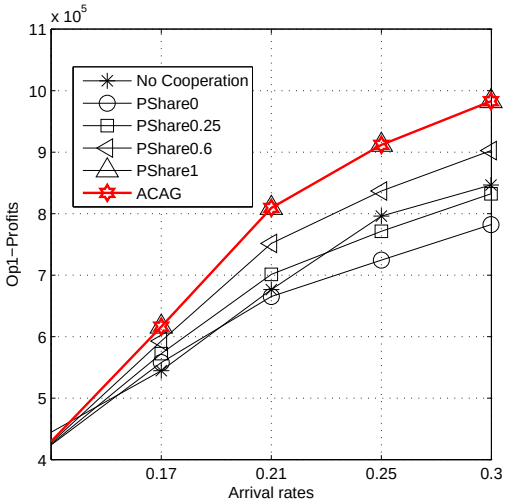
We consider the sharing system *Sys3* formed by three operators Op_1, Op_2 and Op_3. The delivered parameters and the service prices for the partners are depicted in Table 4.1, for each model **BSBC** and **BSBP**. We use the same simulation framework presented in section 3.3, with an arrival interval vector $1/\lambda = 6, 4.8, 4, 3.43, 3, 2.67$. The investigated scenarios are ACAG, MIWC, MCWC, pShare1, pShare0, pShare0.25 with $\alpha = 0.25$ and pShare0.6 with $\alpha = 0.6$.

Table 4.1: Operators' networks parameters and service prices of Sys3

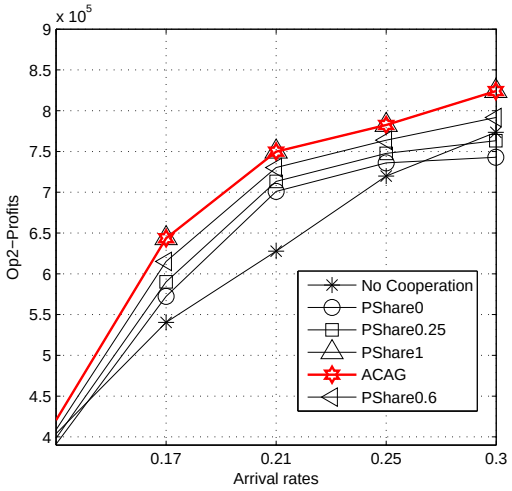
System Model	**Network Settings for [Op_1, Op_2, Op_3]**		
	Capacity (Kb/s)	*Service price(units/Kbytes)*	*QoS specifications [J_M, D_M, BER_M]*
BSBC	[11000, 9000, 5500]	$p_i = 0.5$	[10, 30, 10^{-5}]
BSBP	11000	$p_1 = 0.3$, $p_2 = 0.5$, $p_3 = 0.9$	[10, 30, 10^{-5}]

4.4.1.1 Pricing Scenarios Comparison in BSBC

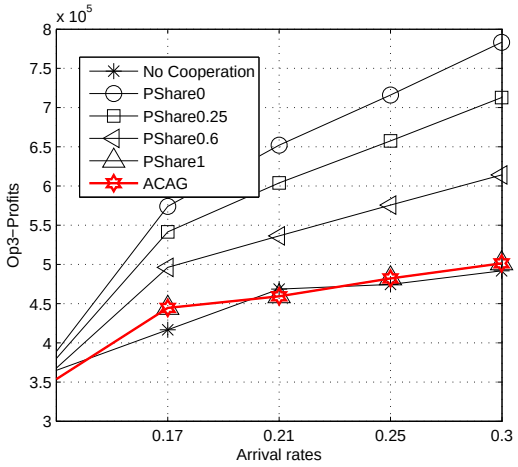
In **BSBC**, we are interested to show the profit improvements induced by each pricing scenario, ACAG, MIWC, MCWC and pShare α , in order to conclude to the best scenario in this model. Figures 4.1a, 4.1b and 4.1c show the profit achievements in function of the arrival rates for Op_1, Op_2 and Op_3, respectively. The results are presented for the investigated pricing scenarios in addition to the case where no inter-operators agreement is made (No cooperation scenario). In the considered model, **BSBC**, all operators adopt the same service price p, deliver the same QoS parameters but share different capacities. First, note that **ACAG** produces the same profits as the pShare1 scenario, for all operators, which is evident since $p_1 = p_2 = p_3$. The proposed scenarios guarantee high profits for the operator deploying a high capacity, as for Op_1 and Op_2, but this is not the case regarding the achieved profits of Op_3, sharing the lowest capacity. The scenario **ACAG**, retaining the same price for clients and partners ($Cs_i = p_i$), guarantees the highest transaction cost (0.5 units/Kbytes) for the S-op compared to the pShareα scenarios. Thus, as much the cooperating operator can serve guest users as much it gets profits, it is the case for Op_1 and Op_2 . However, when the operator wants to improve its user acceptance with a lot of client transaction to another S-op, high charges have to be paid. With the pShare0 scenario, the H-op keeps all its client payment and the S-op looses additional revenues from guest user. This scenario causes a lot of losses for Op_1, at high system arrival while it is serving a high number of guest users, without additional revenues that may recover charges or probable client payments. The results are the same for Op_2. These results begin to change with pShare α scenarios, when the value of α increases, thus increasing the share of the S-op. Conversely, pShare α scenarios guarantee more profit benefits for Op_3, these benefits increase where the value of α is smaller keeping a larger share of the user payment to his H-op. We can conclude that, in the case where the service prices of the operators are approximatly similar, our proposed pricing scenario ACAG guarantees the best profits for the operators having an appropriate amount of shared capacity.



(a) Op1's achieved profits in BSBC



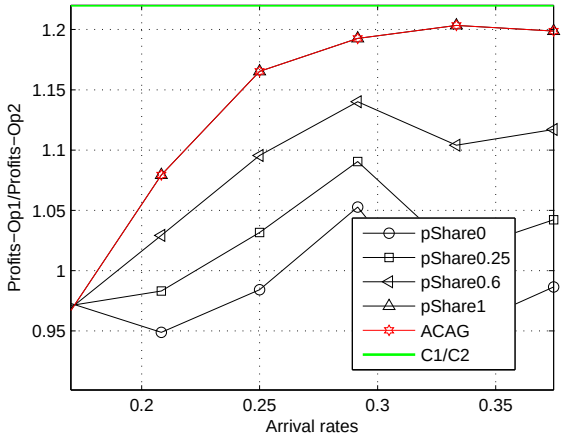
(b) Op2's achieved profits in BSBC



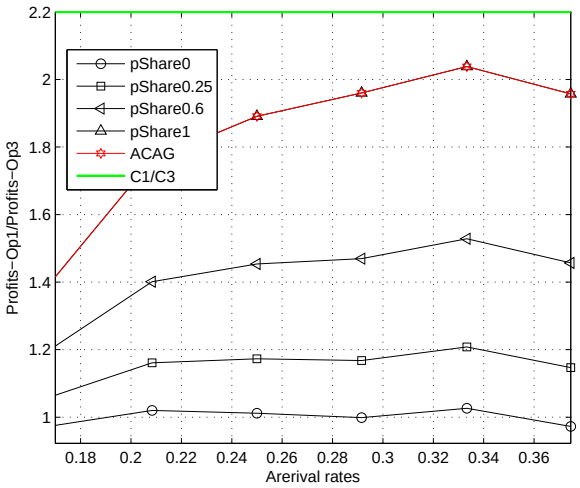
(c) Op3's achieved profits in BSBC

Figure 4.1: Operators's Achieved Profits in BSBC

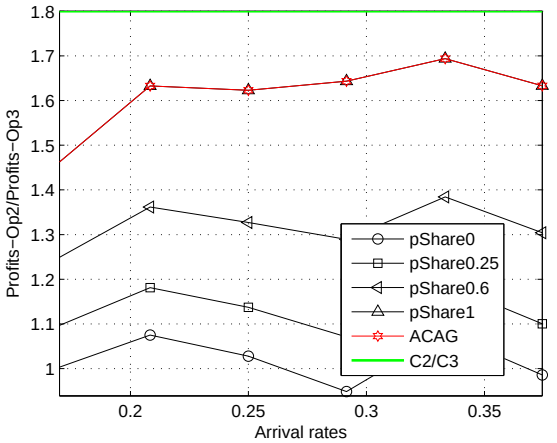
Moreover, we can show that, in a sharing system, **ACAG** guarantees the best profit on investment for all partners. In fact, if we compare the ratio between the capacities of two partners and the ratio between the achieved profits of these partners, only **ACAG** can guarantee a profits ratio close to the capacity ratio. Figures 4.2a, 4.2b and 4.2c show the ratio between the achieved profits of $Op_1$and Op_2, $Op_1$and Op_3, and $Op_2$and Op_3, respectively. Note that the capacity ratio of $Op_1$and Op_2 is $\frac{C_1}{C_2} = 1.22$, of $Op_1$and Op_3 is $\frac{C_1}{C_3} = 2.2$ and $\frac{C_2}{C_3} = 1.8$ is the ratio of the capacity of Op_2 and Op_3. The profits ratio of two partners is an increasing function of the arrival rates with **ACAG**. Moreover, at high arrival rates where sharing is more efficient, this ratio converge to the capacity ratio of these two partners. With pShareα scenarios the profit ratio is lower than the capacity ratio, and it approaches this ratio when the value of α increases.



(a) Ratio of Op1 and Op2 profits



(b) Ratio of Op1 and Op3 profits



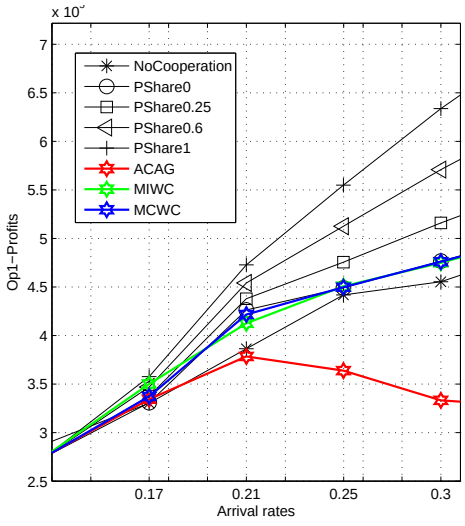
(c) Ratio of Op2 and Op3 profits

Figure 4.2: Partners' profits ratio in BSBC

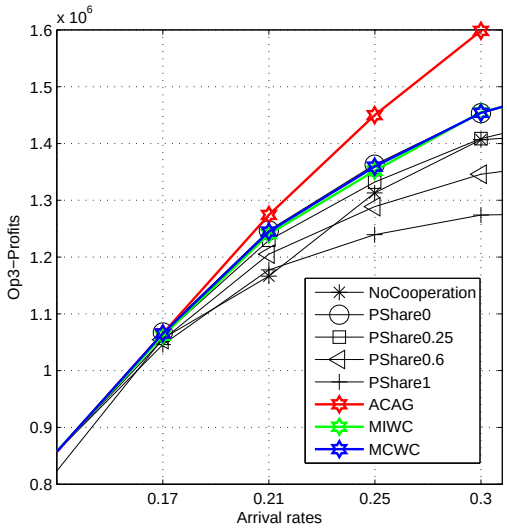
4.4.1.2 Pricing Scenarios Comparison in BSBP:

As stated in BSBP model, the operators set different service prices ($p_1 < p_2 < p_3$), deploy the same capacity and are able to deliver the same QoS parameters. In this case, we are interested to show the profit achievement for the operator Op_1 setting the cheapest service price, and the operator Op_3 setting the most expensive service price .

Figures 4.3a and 4.3b show the profits achieved by Op_1 and Op_3, respectively. Results show that with the proposed pricing scenarios ACAG, MIWC and MCWC, Op3 could maximize its profits especially for high system arrivals, where other price sharing scenarios cause losses. In fact, Op3 could achieve the highest profits with ACAG. Remember that with ACAG, each operator i sets Cs_{i} equal to the the client service price p_{i}, with MIWC chooses Cs_{i} equal to the highest service price in the sharing system, p_3 , and with MCWC chooses the lowest service price, thus p_1. For Op_1, MIWC and MCWC could improve its profits comparing to no Cooperation scenario, but these profits are higher with the considered pShare α scenarios. Scenario ACAG causes losses for Op_1 comparing to no Cooperation scenario. In fact, at high system arrivals, this operator transfer its clients with high rates, while other partners in the system are setting higher service prices, thus higher Cs. Therefore, Op_1 has to pay high charges, while serving guest users do not assure enough revenues to recover these transaction fees. Hence, ACAG is to be avoided by the operator setting the lowest service price.



(a) Op1's achieved profits in BSBP



(b) Op3's achieved profits in BSBP

Figure 4.3: Operators's Achieved Profits in BSBP

4.5 Best Pricing Scenario

In order to find the optimal pricing scenario to be adopted for the transaction cost and accomplish the access selection for a user transaction, we model, in this section,

the interaction between the sharing partners as a Stackelberg game [OR94]. This type of games is known as Leader Follower game, where the sharing operators are the players, the available S-ops for the selection are considered as leaders and the H-ops of the transferred users are the followers.

4.5.1 Transaction Pricing and Access Selection (TPA) Game

We consider a two stages leader-follower TPA game, where the N sharing partners are the players. On a transaction event, the H-op of the transferred user is the follower and the $N-1$ available S-op are the leaders. In the first stage of the game, the leaders announce their transaction cost $Cs = [Cs_1, Cs_2, ..., Cs_{N-1}]$ in a simultaneous play, in order to maximize their global profits $V = [V_1, V_2, ..., V_{N-1}]$. The value of Cs_i depends on the adopted pricing scenario. In the second stage of the game, given the transaction cost for every S-op (the leaders), the H-op (follower) chooses the best S-op that maximizes its payoff 4.4.

The payoff of the H-op, U_H , is a combination of the transferred user utility and the transaction profit, it is equal to the opposit of S_i^{NP-BPA} in equation 3.6 in subsection 3.2.3, such that:

$$U_H = Wop * (p - Cs_i) - Wu * |S_u - S_i'^{SAW}| \tag{4.1}$$

where S_u and $S_i'^{SAW}$ are calculated using equations 3.3 and 3.4, respectively. Hence, the vector $Cs = [Cs_1, Cs_2, ..., Cs_{N-1}]$ is defined as the strategy vector of the leaders in the first stage and the access selection decision is the strategy of the follower in the second stage. Subsequently, the best response of this stage is to select the S-op that maximizes both the user and its H-op satisfaction in terms of QoS and profits, thus maximizing U_H. Then, based on the decision of the follower, the best response of a S-op i is the optimal price Cs_i^* for which its global profit, $V_i(Cs_i^*, Cs_j^*)$ $i \neq j$, $i, j = 1, .., N-1$, is maximized given the price Cs_j^* offered by the other S-op $_j$. Accordingly, when available S-ops, the leaders, announce their Cs simultaneously, a Nash equilibrium can be attained giving the set $Cs^* = [Cs_1^*, Cs_2^*, ..., Cs_{N-1}^*]$ such that none of the operators can increase its profit by choosing a different transaction cost, without degrading the profit of the other players. For the leaders' strategies, we consider ACAG, MIWC, MCWC, pShare0, pShare1 and pShareL scenarios.

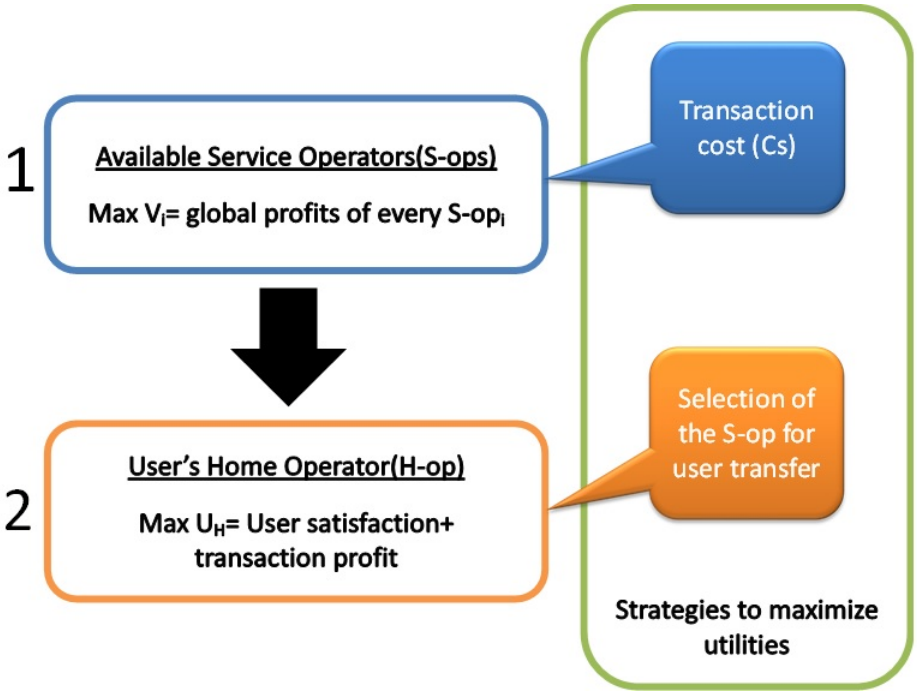


Figure 4.4: Transaction Pricing and Access selection Game Hierarchy

4.5.2 TPA Game Equilibrium

The **TPA** game solution consists of finding the equilibrium set of the operators' transaction costs $Cs^* = [Cs_1^*, Cs_2^*, ..., Cs_{N-1}^*]$, giving the access selection decision of the followers. Therefore, we consider the sharing system *Sys3* of three partners Op_1, Op_2 and Op_3, and we examine two cases of the financial agreement. The first one, when all the partners agree to adopt the same pricing scenario among ACAG, MIWC, MCWC and pShareα. In this case, the solution of the TPA game is denoted by U-TPA (Uniform TPA) equilibrium. The second one, when each operator of *Sys3* decides to adopt its proper pricing scenario, independently of the decision of other partners. In this case, the solution of the TPA game is denoted by F-TPA (Free TPA) equilibrium.

Because of the complexity of finding a formal expression of the global profits for the operators of *Sys3*, the resolution of the TPA game will be based on the numerical values of the achieved global profits obtained from extensive simulations. These simulations are made for every possibility of financial agreement depending on the choice of each partner in *Sys3*.

The delivered parameters and service prices for each operator in *Sys3* are depicted in Table 4.2. For an accurate analysis we kept the same QoS specifications for all partners. Hence, the capacity and the service price are the principal elements affecting our results. Simulations are performed with $1/\lambda = [24\,12\,8\,6\,4.8\,4\,3.43\,3\,2.67]$ and $1/\mu = 4$min, for a duration of 1200 seconds.

Table 4.2: The delivered parameters and service price of Sys3

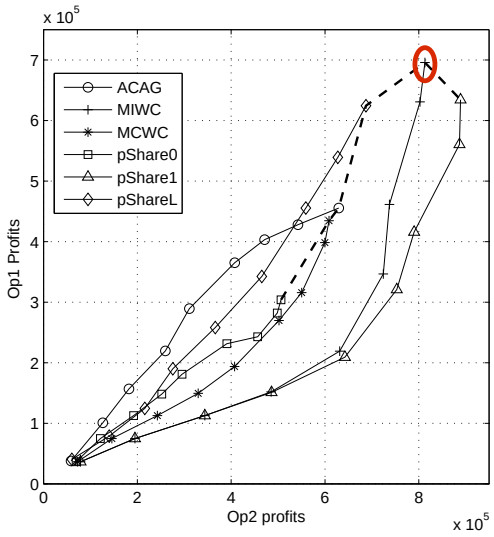
Operator i	*Bandwidth (kbps)*	*QoS specifications [J_M, D_M, BER_M]*	*Service price p (units/Kbytes)*
Op_1	11000	[10, 30, 10^{-5}]	0.3
Op_2	9000		0.5
Op_3	1700		0.9

4.5.2.1 U-TPA Equilibrium

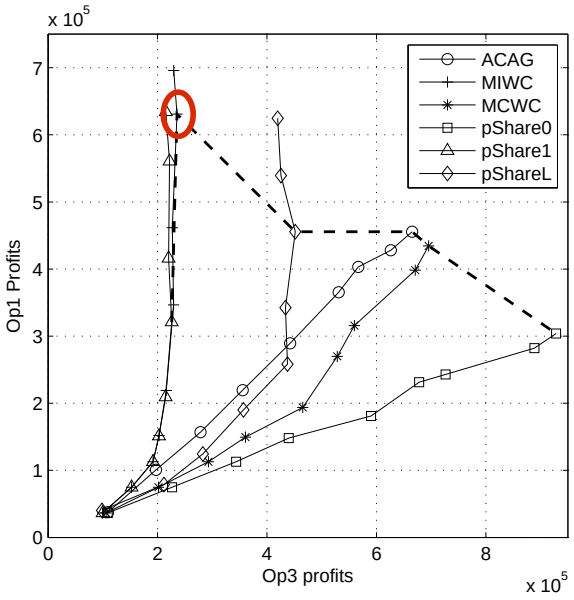
In Leader-Follower games, backward induction is used to attain the equilibrium [OR94]. First the maximization problem in stage II is solved, then this solution is used in order to maximize the problem in stage I. Therefore, simulations are performed for all possible pricing strategies $Cs = [Cs_1, Cs_2, Cs_3]$ of stage I, and at each user transaction, the selection decision is made in order to maximize U_H. At the end of a each simulation, the resulting payoffs V_1, V_2 and V_3 for each player are plotted in the utility space (V_i,V_j) to find the equilibrium strategy, thus best scenario. This space is used in order to deduce the outcomes of the game between each pair of players, and the solution of stage I is a Nash equilibrium for the simultaneous play of the Leaders [CSMW02]. Nash equilibrium point gives the set of prices such that none of the operators can increase the profit by choosing a different price, given the price offered by the other service operator.

Figures 4.5a, 4.5b and 4.5c show the equilibrium pricing scenario for each pair of players $Op_1 - Op_2$, $Op_1 - Op_3$ and $Op_2 - Op_3$, respectively. For every set of strategies Cs, we obtain a curve in the space (V_i, V_j). Therefore, six curves are showed in each figure considering ACAG, MIWC, MCWC and pShare0, pShare1 and pShareL scenarios . Graphically, when we plot V_j in function of V_i, the point of the vertical tangent to the curve corresponds to maximum of V_i. Thus, in our utility space, and for each pricing scenario curve we find the points of the vertical tangent. Then, connecting these points yields to the dashed curve in figures 4.5a, 4.5b and 4.5c, it represents the outcomes of the game for different price scenarios. The best response of the game corresponds to the maximum point of the dashed curve. This method used in [CSMW02], and its useful to find the U-TPA equilibrium, i.e when the strategies of Cs follow the same pricing scenarios.

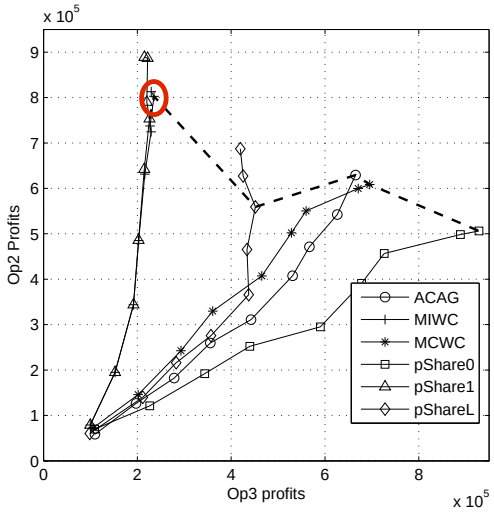
Figure 4.5a shows the profit V_1 of Op_1 in function of V_2 of Op_2, we find the maximum points of V_2 and we connect these points with the dashed curve. The maximum of this curve corresponds to equilibrium point defined by the MIWC scenario, thus $Cs_1^* = 0.9\, and\, Cs_2^* = 0.9$ which is the higher service price in the sharing system, and adopted by Op_3, according to Table 4.2. Figure 4.5b represents the profit of V_1 of Op_1 in function of V_3 of Op_3. Similarly, the best response of $Op_1 - Op_3$ play is reach with MIWC scenario, thus $Cs_1^* = 0.9\, and\, Cs_3^* = 0.9$. Moreover, the equilibrium of $Op_2 - Op_3$ play is attained also with MIWC as shows figure 4.5c, and thus $Cs_2^* = 0.9\, and\, Cs_3^* = 0.9$. We can conclude that the optimal pricing scenario to adopt in Sys3 is MIWC.



(a) Equilibrium scenario for Op1 and Op2



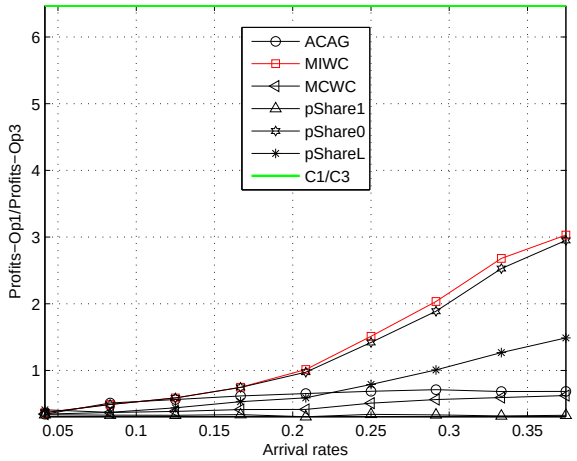
(b) Equilibrium scenario for Op1 and Op3



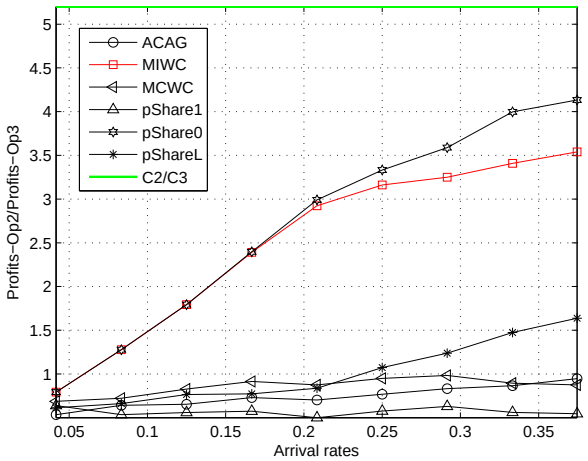
(c) Equilibrium scenario for Op2 and Op3

Figure 4.5: Equilibrium scenario for each pair of players

In fact, with **MIWC**, the operators who share high capacities guarantee the best profit on investment. The comparison of the ratio between the capacities and the ratio between the achieved profits of $Op_1$and Op_3, and the profits of $Op_2$and Op_3, in figures 4.6a and 4.6b respectively, shows that **MIWC** can guarantee a profits ratio close to the capacity ratio. Note that the capacity ratio of $Op_1$and Op_2 is $\frac{C_1}{C_2} = 1.22$, of $Op_1$and Op_3 is $\frac{C_1}{C_3}$ =6.47 and $\frac{C_2}{C_3} = 5.29$ is the ratio of the capacity of Op_2 and Op_3.



(a) Ratio of Op1 and Op3 profits-General case



(b) Ratio of Op2 and Op3 profits-General case

Figure 4.6: Partners' Profit ratio-General case

4.5.2.2 F-TPA Equilibrium

With free transaction pricing, each operator is free to choose the pricing scenario that may maximize its own profits. Considering ACAG, MIWC, MCWC and pShareL, it increases the number of the transaction cost combinations $Cs = [Cs_1, Cs_2, Cs_3]$ to 64, which increases as well the number of curves and makes the game resolution very difficult using the utility space. Hence, it is more suitable to use the payoff tables of a strategic

game to find the F-TPA equilibrium. In a payoff table columns and rows represent the strategies of the column player and the row player, respectively, and each cell contains the payoffs of of all players. In our case, each table contains four columns and four rows, with Op_3 as the column player and Op_2 as the row player. Op_1 is considered as the major player which shares the highest capacity, thus, for each strategy taken by Op_1we construct the payoff tables containing the payoffs pay1, pay2 and pay3 for Op_1, Op_2 and Op_3, respectively. We obtain four payoff tables in total .

Tables 4.3, 4.4, 4.5 and 4.6 represent the strategic game with three players Op_1, Op_2 and Op_3, when Op_1 takes the actions ACAG, MIWC, MCWC, and pShareL for the transaction cost, respectively. The Nash equilibrium of a strategic game is the strategy (action) profile with the property that no player can increase her payoff by choosing a different action, given the other players' actions. In our case, their exist 64 action profile which are the triplets $[Cs_1, Cs_2, Cs_3]$. A strategic game may have no Nash equilibrium, may have a single Nash equilibrium, or may have many Nash equilibria. In order to find the F-TPA equilibrium, we determine the best response, $Cs_j^* = [Cs_1^j, Cs_2^{j*}, Cs_3^{j*}]$, $j = 1, .., 4$, of Op_2 and Op_3in each table j, thus for each strategy taken by Op_1. Then, we find the dominant strategy of Op_1, Cs_j^* , that maximizes its payoff. In other words, F-TPA equilibrium is equal to Cs^* such that $V_1(Cs^*) = \max_j(V_1(Cs_j^*))$. The best response of the first player is defined as the action of this player that maximizes its payoff, given the second player's actions.

Consequently, for each action (strategy) of Op_1, we find the best response of Op_2 and Op_3. In the tables the best response of each players are uderlined. and the Nash equilibrium of each strategic game is in bold and its equal to $[Cs_2^{j*}, Cs_3^{j*}] = [0.9, 0.9]\ \forall j$. In other words, the best scenario to adopt by Op_2 is **MIWC** and the best scenario to adpt by Op_3 is **MIWC** or **ACAG,** whatever is the action of Op_1. In fact, Op_3 is setting the higher service price, $p_3 = 0.9$, for this reason **MIWC** and **ACAG** gave the best response. Comparing the payoffs of Op_1 for each obtained response Cs_j^*, we find the maximumm value in Table 4.4 with $V_1(Cs^*) = 756036.7227$ units. Hence, we can say that the F-TPA equilibrium scenarios is obtained when all the partners adopt MIWC, or when Op_3 adopts **ACAG** given that Op_1 and Op_2 adopt **MIWC**. The latter result occured because Op_3 sets the highest service price in the system. We can conclude that in *Sys3*, there is no benefits for a free transaction pricing, all partners are recommended to have the same pricing scenario, i.e, for a uniform transaction pricing and to choose their transaction cost equal to the higher service pricing offered by the sharing partners.

4.6 Conclusion

In this chapter, we proposed three pricing scenarios, ACAG, MIWC and MCWC for the inter-operators transaction cost, that may be adopted in a sharing system. We decided that the transaction cost must be related to the service price of the sharing partner since

this price affects the selection decision and the income flow of the operators. Besides it is a parameter that no partners renounce to share, and any dynamic chagement of this price will affect the transaction cost in the system. The profitability of these scenarios was studied in a three partners sharing system, and the decision of the best scenario to adopt was taken using a Leader-Follower game. Results showed that profit improvement is always achieved through cooperation even though the operator is setting the cheapest or the most expensive service. Our pricing scenarios guarantee higher profits comparing to sharing price scenarios, and they succed to share profits on capacity investment, in a fair way. Our pricing scenarios are recommended for the operator sharing the higher capacity, and ACAG is to be avoided by the operator setting the lowest service price in the sharing system. Finaly, all partners are advised to adopt the same pricing scenario, and when the partners set different service prices, the best is to adopt MIWC scenario, in order to set the transaction cost to the highest service price in the sharing system, and satisfy all partners.

Table 4.3: Op1, Op2 and Op3 Payoffs when Op1 chooses ACAG

			Op3			
			ACAG	*MIWC*	*MCWC*	*pShareL*
Op2	*ACAG*	pay1=	432327.102	432327.102	439451.271	440664.3491
		pay2=	659518.3414	659518.3414	665784.6872	665542.8732
		pay3=	639741.6688	639741.6688	626351.154	625379.89
	MIWC	pay1=	412676.4354	412676.4354	419800.6044	421013.6825
		pay2=	**807848.5615**	**807848.5615**	814114.9073	813873.0933
		pay3=	**511062.1154**	**511062.1154**	497671.6006	496700.3365
	MCWC	pay1=	442152.4354	442152.4354	449276.6043	450489.6824
		pay2=	585353.2314	585353.2314	591619.5772	591377.7632
		pay3=	704081.4456	704081.4456	690690.9308	689719.6667
	pShareL	pay1=	443932.0948	443932.0948	451056.2638	452269.3419
		pay2=	696966.4024	696966.4024	703232.7482	702990.9342
		pay3=	590688.6151	590688.6151	577298.1003	576326.8362

Table 4.4: Op1, Op2 and Op3 Payoffs when op1 chooses MIWC

			Op3			
			ACAG	*MIWC*	*MCWC*	*pShareL*
Op2	*ACAG*	pay1=	775687.3894	775687.3894	782811.5583	784024.6364
		pay2=	591265.5263	591265.5263	597531.8721	597290.0581
		pay3=	364634.1967	364634.1967	351243.6819	350272.4178
	MIWC	pay1=	756036.7227	756036.7227	763160.8917	764373.9698
		pay2=	**739595.7464**	**739595.7464**	745862.0922	745620.2782
		pay3=	**235954.6432**	**235954.6432**	222564.1284	221592.8643
	MCWC	pay1=	785512.7227	785512.7227	792636.8917	793849.9697
		pay2=	517100.4162	517100.4162	523366.762	523124.948
		pay3=	428973.9734	428973.9734	415583.4586	414612.1945
	pShareL	pay1=	787292.3821	787292.3821	794416.5511	795629.6292
		pay2=	628713.5873	628713.5873	634979.9331	634738.1191
		pay3=	315581.1429	315581.1429	302190.6281	301219.364

Table 4.5: Op1, Op2 and Op3 Payoffs when op1 chooses MCWC

			Op3			
			ACAG	*MIWC*	*MCWC*	*pShareL*
Op2	*ACAG*	pay1=	432327.102	432327.102	439451.271	440664.3491
		pay2=	659518.3414	659518.3414	665784.6872	665542.8732
		pay3=	639741.6688	639741.6688	626351.154	625379.89
	MIWC	pay1=	412676.4354	412676.4354	419800.6044	421013.6825
		pay2=	**807848.5615**	**807848.5615**	814114.9073	813873.0933
		pay3=	**511062.1154**	**511062.1154**	497671.6006	496700.3365
	MCWC	pay1=	442152.4354	442152.4354	449276.6043	450489.6824
		pay2=	585353.2314	585353.2314	591619.5772	591377.7632
		pay3=	704081.4456	704081.4456	690690.9308	689719.6667
	pShareL	pay1=	443932.0948	443932.0948	451056.2638	452269.3419
		pay2=	696966.4024	696966.4024	703232.7482	702990.9342
		pay3=	590688.6151	590688.6151	577298.1003	576326.8362

Table 4.6: Op1, Op2 and Op3 Payoffs when op1 chooses pShareL

	Op3					
			ACAG	*MIWC*	*MCWC*	*pShareL*
Op2	*ACAG*	pay1=	604612.3019	604612.3019	611736.4709	612949.549
		pay2=	643897.5383	643897.5383	650163.8841	649922.0701
		pay3=	483077.2721	483077.2721	469686.7573	468715.4932
	MIWC	pay1=	584961.6352	584961.6352	592085.8042	593298.8823
		pay2=	**792227.7584**	**792227.7584**	798494.1042	798252.2902
		pay3=	**354397.7186**	**354397.7186**	341007.2038	340035.9397
	MCWC	pay1=	614437.6352	614437.6352	621561.8042	622774.8823
		pay2=	569732.4283	569732.4283	575998.7741	575756.9601
		pay3=	547417.0488	547417.0488	534026.534	533055.2699
	pShareL	pay1=	616217.2946	616217.2946	623341.4636	624554.5417
		pay2=	681345.5993	681345.5993	687611.9451	687370.1311
		pay3=	434024.2183	434024.2183	420633.7035	419662.4394

Chapter 5

Inter-operators Agreement for Resource Sharing

When a number of operators decide to share their access, it is important to determine how to share and the appropriate access control mode to adopt. Among the kinds of access control modes, the hybrid access mode was found the most promising because it allows operators to give preferential access to their own subscribers, while other guest users can only access a restricted amount of resources. This chapter considers a hybrid access mode in a three partners sharing system. It shows how resource reservation can guarantee client satisfaction by reducing the blocking rates. In addition, the inter-operators service pricing and the profitability of the previously proposed scenarios are investigated in a hybrid access mode. Further, an economic framework based on game theoratical analysis is proposed. The framework formulates a sequentiel Stackelberg game in which the sharing partners decide the proportion of resources they will be shared with other partners, and the transaction pricing scenario to adopt in order to maximize their profits. We demonstrate the existence of Equilibria in the game, and derive the most effective strategies within an exemple of three operator system.

5.1 Introduction

In previous chapters, open access mode was adopted. Results showed that the amount of shared capacity affect how much an operator can benefit from sharing the access with other operators. Besides, in chapter 3, results showed that when an operator shares a high capacity, it will acts as a service operator for guest users with high rates, which may affect negatively its client (own subscribers) acceptance an thus its incomes. Therefore, a common solution is to determine a specific amount of resources to be shared with guest users in a hybrid access mode. Accordingly, we consider the sharing system of three partners, denoted by *Sys3*, and we choose different sharing factors γ , which is a percentage of the operator resources limited for guest users. How much to share and the

effect of limiting the shared capacity on the subscribers satisfaction and operators profits, are subject of the study in this chapter.

Along this chapter, an operator "client" is refered to the own subscribers of the operator and "guest" is the mobile user transferred from other partners in the sharing system. We summarize the investigated parameters as follow:

- p_i: service price of an operator i paid by its client.
- Cs_i: transaction cost of an operator i paid by the H-op of a guest user.
- γ_i: sharing factor of an operator i equal to the fraction of the shared resource that guest users .

5.2 Static Resource Sharing

In static resource sharing, we suppose that all partners in the system decide to share a fixed percentage and without changing it during the hole period of sharing. In this case, we study the performance of a three partner sharing system, *Sys3,* we track the changement of the blocking rates, as well as the achieved profits, for different values of γ. Without loss of generality, we consider the values γ = 10, 20, 30 and 50% for our study. The delivered parameters and service prices of the sharing partners, Op_1, Op_2 and Op_3, are listed in Table 5.1. Note that the considered system, *Sys3,* is identical to the system studied in chapter 3, section3.3, where we showed that the operator sharing the highest capacity with a low transaction cost was penalized by a high service rate . We are interested to show that resource reservation for clients reduces blocking rates. Results are represented for different pricing scenarios ACAG, MIWC and MCWC. Remember that:

- with ACAG each operator of the sharing system sets its transaction cost Cs equal to its service price p, such that $Cs_i = p_i$ for all i = 1, 2 and 3.
- with MIWC all operators set identical Cs equal to the highest service price in the system, such that $Cs = \max_i(p_i)$ i = 1, 2and 3.
- with MCWC all operators set identical Cs equal to the lowest service price in the system, such that $Cs = \min_i(p_i)$ i = 1, 2and 3.

Table 5.1: Partners' delivered parameters and service prices

Operator i	Bandwidth (kbps)	Jitter (ms)	End-to-End Delay (ms)	BER (dB)	service price (unit/Kbytes)
Op_1	1700	6	19	10^{-3}	0.9
Op_2	11000	10	30	10^{-5}	0.1
Op_3	5500	12	45	10^{-5}	0.2

5.2.1 Blocking Rates with Static Resource Sharing

In this subsection, we consider the variation of the blocking rates with respect to the sharing factor and for each pricing scenario. Figures 5.1, 5.2 and 5.3 show the blocking rates for Op_1, Op_2 and Op_3, respectively. The open access case corresponds to the value of $\gamma = 100\%$, and it represents the model adopted in chapter 3, where $Op_2$was penalized by an increase in the blocking rates after cooperation, since it serves guest with high rates, see Table3.5.

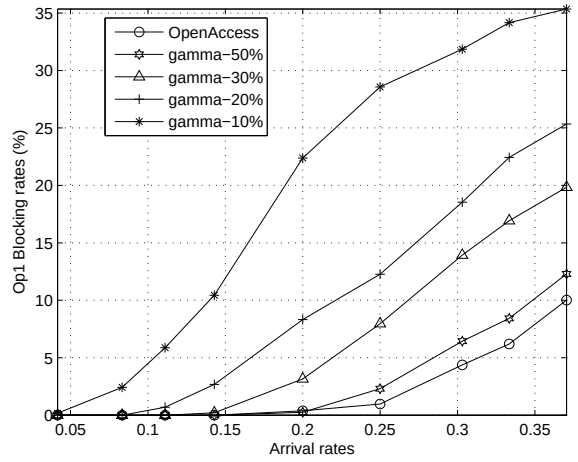
Op_1's blocking rates- Figures 5.1a, 5.1b and 5.1c show the blocking rates for Op_1 when adopting ACAG, MIWC and MCWC, respectively. It is clear that the blocking rates of Op_1 decrease when the partners share more capacity, whatever is the adopted pricing scenario. These rates achieve the lowest values in the open access mode with $\gamma = 100\%$, and are high even at low arrival rates with $\gamma = 10\%$. In fact, Op_1 has a limited capacity and transfer clients with high rate. Consequently, when partners reduces the amount of shared capacity it reduces the acceptance of guest users, thus, the probability of blocking Op_1's clients increases.

The same behavior is detected when the operators change the pricing scenario from ACAG to MIWC and MCWC. Further, for the same sharing factor, the recorded blocking rates are the same for all pricing scenario (considering the interval of confidence).

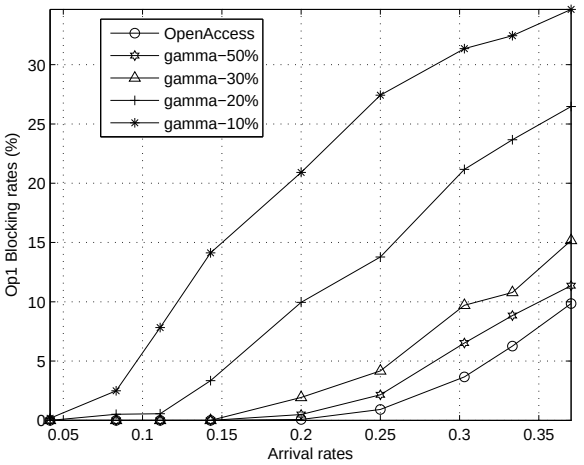
Op_2's blocking rates- Figures 5.2a, 5.2b and 5.2c show the blocking rates for Op_2 when adopting ACAG, MIWC and MCWC, respectively. For low arrival rates, below 0.2, the blocking rates of Op_2 with different γ and for all pricing scenarios are null. These rates increase with the system arrival rate, *i.e.* when the system becomes more loaded, and are higher when Op_2 shares more capacity with partners. Op_2 serves high numbers of guest users, thus, with small value of γ ($\gamma = 10\%$), the blocking rates are maintained below 2%, with all pricing scenarios. Hence, reducing the amount of shared capacity helps Op_2 to limit the guest flow and guarantee its clients satisfaction.

Op_3's blocking rates- Figures 5.3a, 5.3b and 5.3c show the blocking rates for Op_3 when adopting ACAG, MIWC and MCWC, respectively. Results show the same as for Op_1 ; the blocking rates decrease when the partners share more capacity, whatever is the adopted pricing scenario. However, for Op_3 these rates are null at low arrival rates.

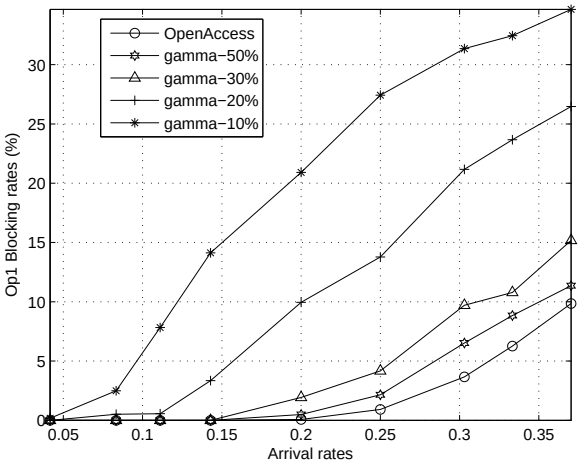
We can conclude that the value of γ affects the clients satisfaction of all partners. Besides, the operator sharing large capacity and serving a large number of guest users have to reduce the sharing factor in order to guarantee better performance in terms of blocking rates. However, this decision may affect clients satisfaction of other partners having smaller capacity and performing a lot of transactions.



(a) Op1's Blocking rates with ACAG

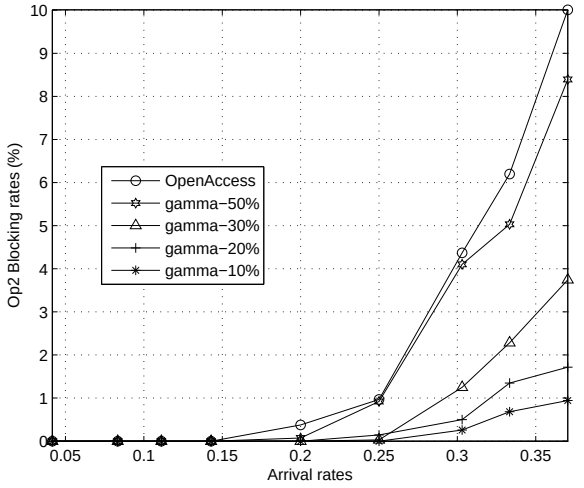


(b) Op1's Blocking rates with MIWC

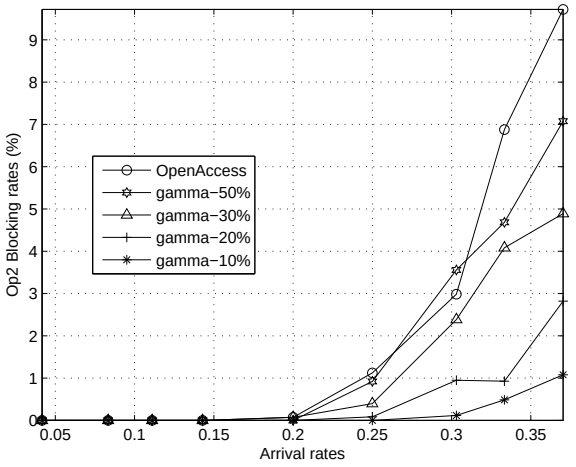


(c) Op1's Blocking rates with MCWC

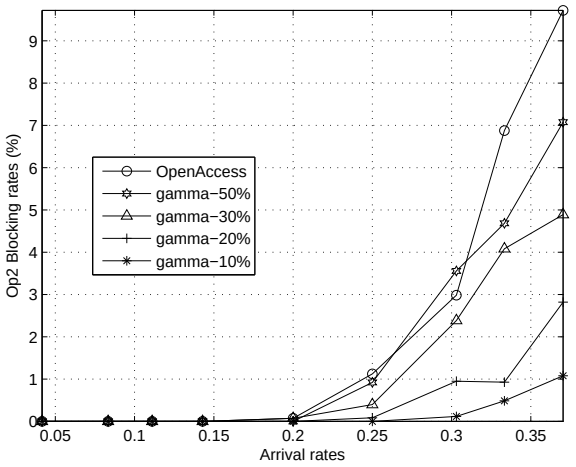
Figure 5.1: Op1's Blocking Rates Comparison with static sharing



(a) Op2's Blocking rates with ACAG

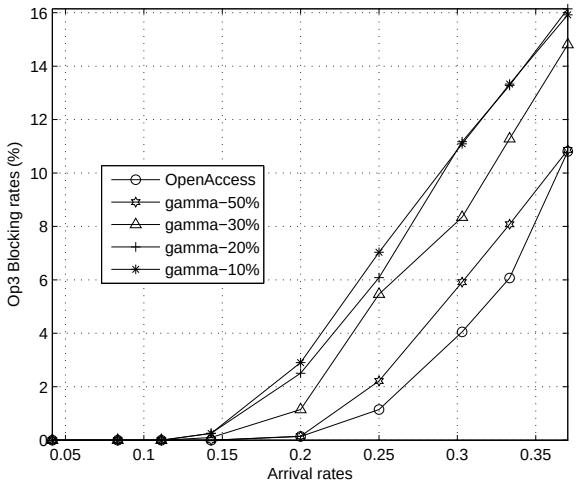


(b) Op2's Blocking rates with MIWC

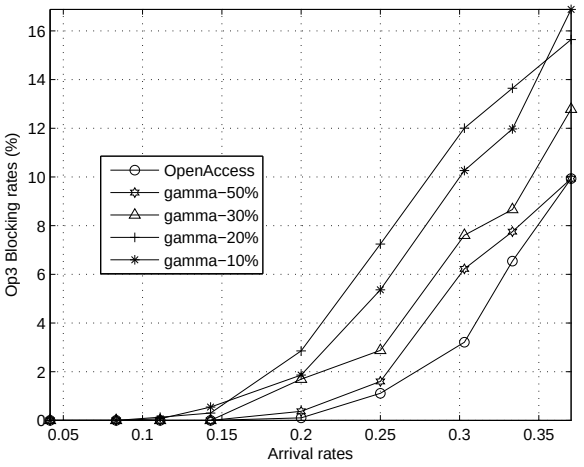


(c) Op2's Blocking rates with MCWC

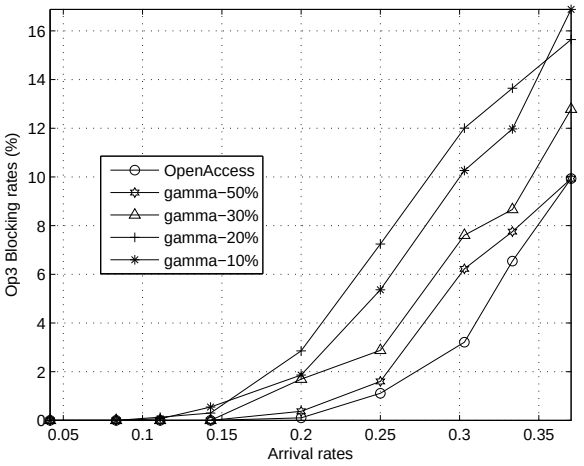
Figure 5.2: Op2's Blocking Rates Comparison with static sharing



(a) Op3's Blocking rates with ACAG



(b) Op3's Blocking rates with MIWC



(c) Op3's Blocking rates with MCWC

Figure 5.3: Op3's Blocking Rates Comparison with static sharing

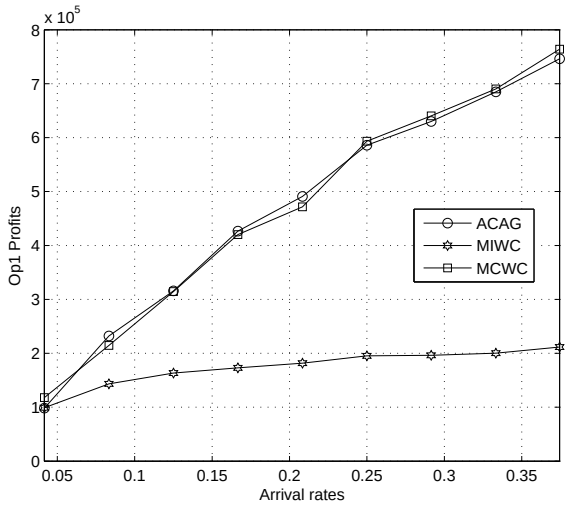
5.2.2 Global Profits with Static Resource Sharing

In this subsection, we represent the variation of the profits with respect to the adopted pricing scenario and for the values of γ = 10, 50 and 100% . Figures 5.4, 5.5 and 5.6 show the achieved profits for Op_1, Op_2 and Op_3, respectively.

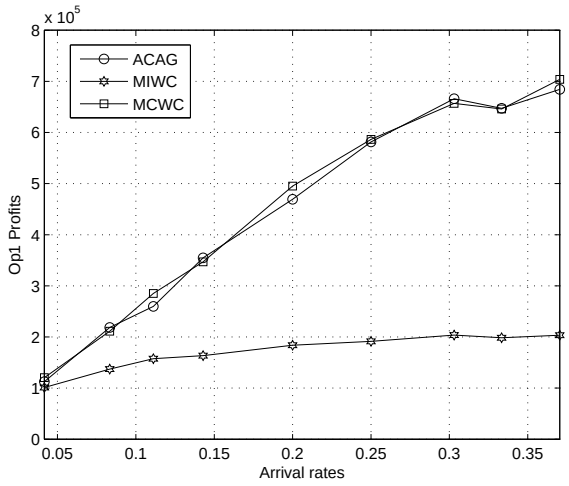
Op_1's global profits- Figures 5.4c, 5.4b and 5.4a show the achieved profits for Op_1 with γ = 100, 50 and 10% , respectively. First, notice that when partners reduce the amount of shared resources, the achieved profits of Op_1 decrease. This operator is sharing the lowest capacity, and its revenue depends strongly on the payment of the transfered users. Therefore, when the partners adopt a low sharing factor γ, the user blockings of Op_1 increase, thus, reducing its profits 5.4c. Second, when the partners adopt ACAG and MCWC the achieved profits of Op_1 are very closed since the majority of the transfered users of Op_1 goes to Op_2 , which sets the lowest service price. With MIWC, Op_1 pays all the users' payment for the transaction cost, and its profit remains the same even when the sharing factor increases. For Op_1, sharing the lowest capacity, the open access mode, with a low transaction cost pricing scenario guarantees the highest profits.

Op_2's global profits- Figures 5.5a, 5.5b and 5.5c show the achieved profits for Op_2 with γ = 100, 50 and 10% , respectively. This operator is sharing the highest capacity in the system, and its profits improvement depends strongly on the transaction cost gained from serving guest users. Therefore, when it increases the sharing factor γ, Op_2 serves more guest users and the achieved profits increase. Moreover, MIWC scenario guarantees the highest profits for Op_2. And the profits achieved with ACAG and MCWC are the same, since Op_2 sets the lowest service price. For Op_2, sharing the highest capacity, the open access mode guarantees better profits, but with the highest transaction cost pricing scenario .

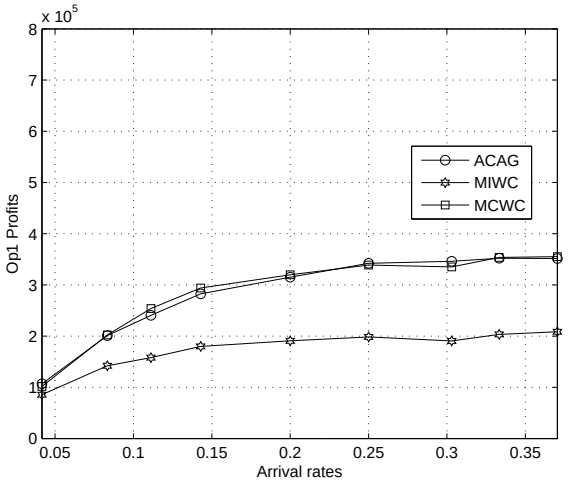
Op_3's global profits- Figures 5.6a, 5.6b and 5.6c show the achieved profits for Op_3 with γ = 100, 50 and 10% , respectively. This operator is sharing a medium capacity, it serves guest users coming from Op_1 at low and medium arrival rates, and transfers its clients to Op_2, at high arrival rates. Thus, the profit improvement of Op_3 depends on the transaction cost gained from Op_1 and the income from transfered users at high arrival rates. Therefore, when partners increase the sharing factor γ, Op_3 serves more guest users and its able to transfer more clients, thus, achieving more profits. Moreover, MIWC scenario guarantees the highest profits for Op_3 especially at low and medium arrival rates, when it acts as a service operator. But at high arrival rates MIWC induces high transaction costs, which degrade its profits. This negative profit variation decreases with the sharing factor where the profits are smaller.



(a) Op1's achieved profits with $\gamma = 100\%$

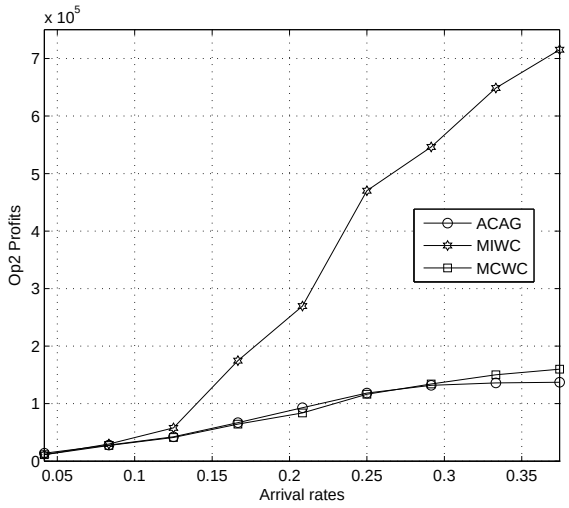


(b) Op1's achieved profits with $\gamma = 50\%$

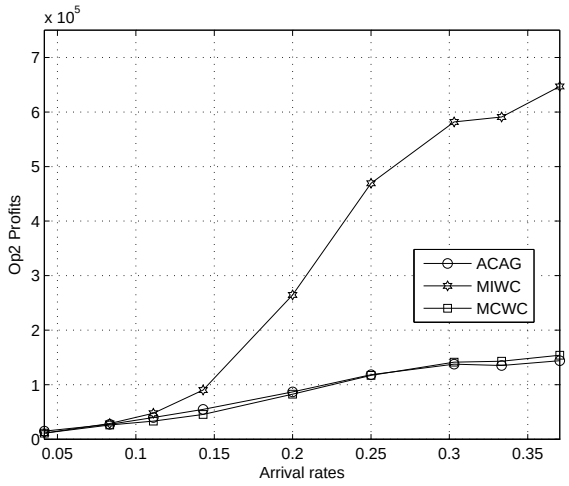


(c) Op1's achieved profits with $\gamma = 10\%$

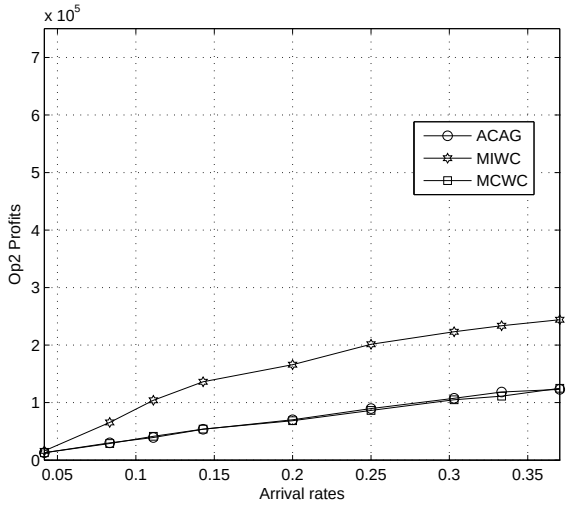
Figure 5.4: Op1's Achieved Profits with static sharing



(a) Op2's achieved profits with $\gamma = 100\%$

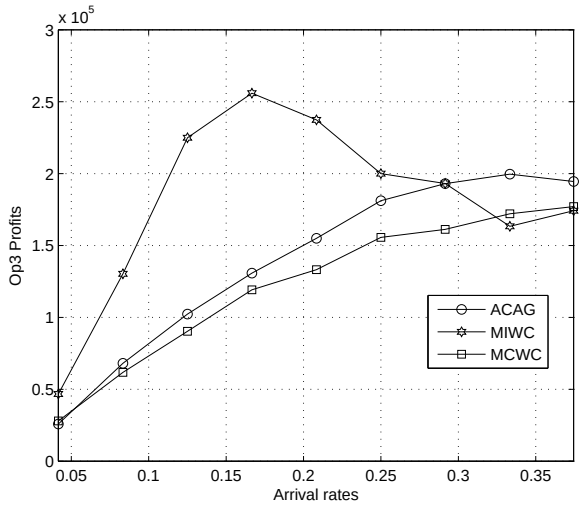


(b) Op2's achieved profits with $\gamma = 50\%$

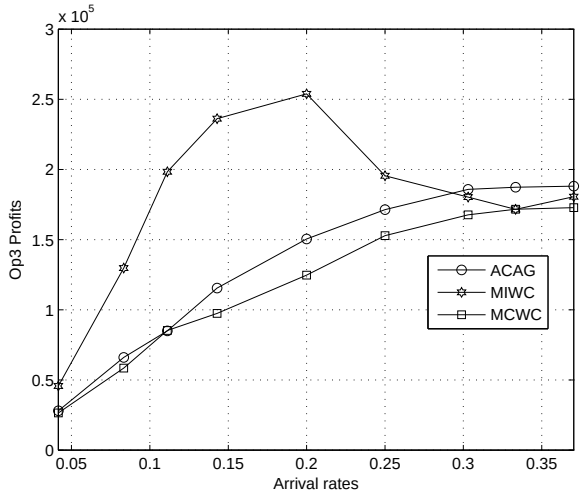


(c) Op2's achieved profits with $\gamma = 10\%$

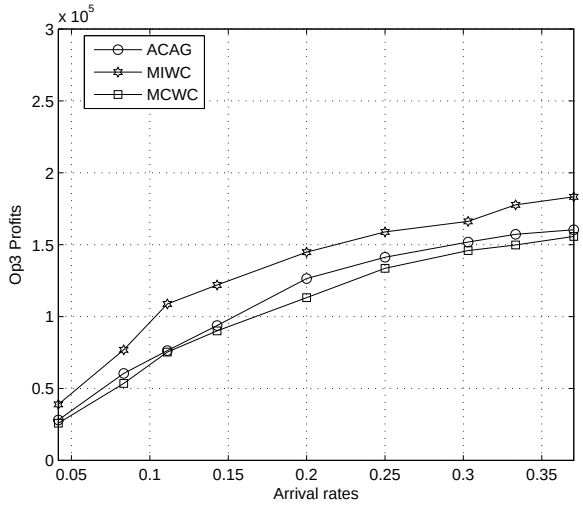
Figure 5.5: Effect of the sharing factor and pricing scenario on the achieved profits of the partner sharing the highest capacity, Op2



(a) Op3's achieved profits with $\gamma = 100\%$



(b) Op3's achieved profits with $\gamma = 50\%$



(c) Op3's achieved profits with $\gamma = 10\%$

Figure 5.6: Effect of the sharing factor and pricing scenario on the achieved profits of Op3

We can conclude that, when the partners of the sharing system increase their sharing factor, higher profits are guaranteed, and the amount of these profits depends on the inter-operator pricing scenario. The open access mode showed better profit achievement for all sharing partners. But, when the system is very loaded, at high arrival rates, this access mode increases the blocking rates of Op_2.

5.3 Resource Sharing and Transaction Pricing (RS-TP) Game

Previous results showed that increasing the sharing factor improves the achieved profits of all sharing partners, but it may affect the blocking rates of the operator having the highest capacity. In fact, results showed that the sharing factor γ , and the transaction pricing scenario for Cs affects simultaneously the profits of the sharing partners and their networks performance. In addition, the decision of one operator of the sharing system, for γ and Cs, affects the payoffs and thus the decision of all other partners. The behavior of each operator, given the actions of other operators, can be analyzed by using non-cooperative game theory [NH08]. Therefore, we define a non-cooperative multilevel sequentiel game for resource sharing and transaction pricing decision, RS-TP game, where the operators of a sharing system are the players.

5.3.1 Problem Formulation

We consider a sharing system formed by I operators, Op_1, Op_2, Op_3...& Op_I, each shares γ_i of their access resources in a multi-operator network and sets Cs_i for the transaction cost. Each operator of the sharing system is characterized by its capacity C_i and the shared capacity $\gamma_i C_i$, and a service price p_i gained when serving a subscriber.

We define the network state of an operator i by (N_i, K_i, X_i, γ_i), where:

- N_i is the total number of users connected to operator i.
- K_i is the total number of operator i clients connected to its network.
- X_i is the total number of operator i guests connected to its network. Such that $N_i = K_i + X_i$.
- γ_i is the resource sharing factor of an operator i, such that $\gamma_i \in [0\,1]$.

We define a two level multi-leader follower game, RS-TP game. At the first level, the operators of the sharing system (the leaders) interact with each others in order to decide the best γ and Cs. The decision at this level is considered with a long time scale, and the corresponding strategy set S_1 is defined as $S_1 = \{Cs_i, \gamma_i; i \in I\}$. At the second level, the home operator of each transferred user (the followers) performs the access selection based

on the shared capacity and the transaction cost of other service operators in the system. The action of the followers is triggered on each transaction event, and the corresponding strategy set S_2 is defined as $S_2 = \{\alpha_{ij};\ i \neq j,\ i,j \in I\}$, where $\alpha_{ij} \in \{0,1\}$, and $\alpha_{ij} = 1$ means that operator i selects operator j for its client service. The hierarchy of the RS-TP game is represented in figure 5.7.

The utility or payoff of a leader is equal to the resulting profit calculated as the income from transfered clients, added to the revenue from guest users minus the transaction cost resulting from users transfer. In order to maximize its utility the operators in the sharing system have to decide about the sharing factor of their access resources $\gamma_i\ i \in I$, and the transaction cost $Cs_i\ i \in I$. Besides when a transaction event occurs, the home operator of the transferred user, the follower, selects the appropriate service operator for its client. The selection decision must be taken in order to minimize the perceived delay by the user. The selection decision of an operator i is determined by the vector $A_i = [\ \alpha_{i1}\ \alpha_{i2}...\alpha_{iI}]$.

Accordingly, the payoffs of the players at the upper level are defined as the profits $P_i\ i \in I$, and at the lower level a cost function for each follower, $U_i\ i \in I$, determines the perceived delay when connecting to S-op.

The choice of the players fits the RS-TP game in our system model, where we assumed that the operators are the decision makers for the access selection, the transaction cost pricing and the amount of shared resources. This adds some complexity in this game, where the same operator acts as a leaders in the upper level and when it transfers a client, acts as a follower in the lower level.

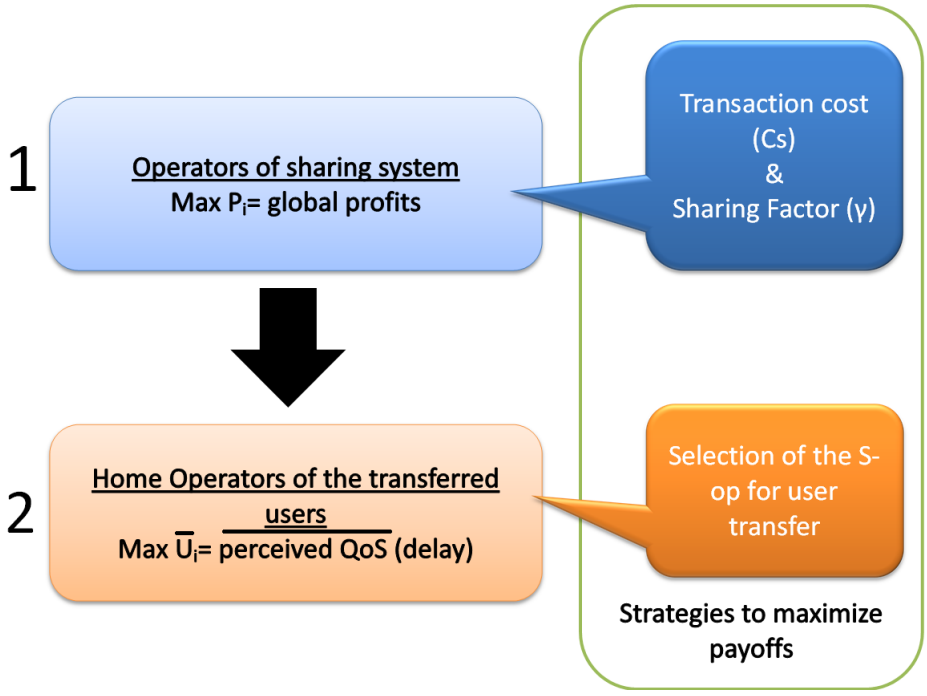


Figure 5.7: RS-TP game hierarchy

5.3.2 RS-TP game payoff development

At the upper level of the RS-TP multi-leaders followers game, the operators of the sharing system behave selfishly in order to maximize their global profit. Note that the actions of each player in S_1 affects mutually the amount of shared resources and the transaction cost, thus, the new incomes from guest users, the additional revenue from transferred clients and the total transaction cost. At this level, the payoff of a player is defined as the global profit, denoted by $P_i(S_1, S_2)$ and it is equal to:

$$P_i(S_1,S_2) = \sum_{j \in I-\{i\}} \alpha_{ij} \cdot (p_i - Cs_j) \cdot \frac{\gamma_j \cdot C_j}{X_j + \sum\limits_{k \in I-\{j\}} \alpha_{kj}} + \sum_{k \in I-\{i\}} \alpha_{ki}.Cs_i \cdot \frac{\gamma_i \cdot C_i}{X_i + \sum\limits_{k \in I-\{i\}} \alpha_{ki}} \quad (5.1)$$

At the lower level, the players' action in S_2, affects the amount of transaction cost to pay and thus the income of the new service operator. At this level, the players (followers) selects the suitable service operator in order to minimize the service delay of the transferred users. The payoff of the player is determined by:

$$U_i(S_1,S_2) = \sum_{j \in I-\{i\}} \alpha_{ij} \cdot \frac{N_j + \sum\limits_{k \in I-\{j\}} \alpha_{kj}}{C_j} \quad (5.2)$$

5.3.3 RS-TP Game Equilibria

We consider a sharing system where the operators behaving selfishly in a RS-TP game. The action of each operator depends on the behaviors of the other operators and the prediction of each transferred user access selection. Accordingly, we intend to explore the existence of a Stackelberg Equilibrium (SE) between the leader level and the follower level, in addition of two Nash Equilibria (NE) within leaders and within followers respectively.

In fact, in a multi-leader follower game, backward induction is adopted. It consist of finding the best response of the leaders after predicting the equilibrium action of the followers, the resolution of such game begins from lower level to the upper level.

Hence, we define $S_2^* = \{\alpha_{ij}^*;\ i \neq j,\ i,j \in I\}$ as the NE strategy set of the followers, if the following condition is satisfied:

$$\forall i,\ \forall j \in I, \quad U_i(S_1, \alpha_{ij}^*, \alpha_{i-j}^*) \leq U_i(S_1, \alpha_{ij}, \alpha_{i-j}^*) \quad (5.3)$$

Symetricaly, we define $\xi^* = \{Cs_i^*,\ \gamma_i^*,\ \alpha_{ij}^*;\ i \neq j,\ i,j \in I\}$ as the SE strategy set of the game, if the following conditions are satisfied:

$$\forall i,\ \forall j \in I,\ P_i(Cs_i^*,\ \gamma_i^*,\ S_2^*) \geq P_i(Cs_i,\ \gamma_i^*,\ S_2^*) \geq P_i(Cs_i^*,\ \gamma_i,\ S_2^*) \quad (5.4)$$

5.3.3.1 Existence of Nash Equilibria

To prove the existence of NE at the upper and lower levels of the game, we have to show that the RS-TP game is a Supermodular game [SPTC15].

Definition 1 A Supermodular Game is a strategic game (S_i, P_i; $i \in I$) where I is the set of players, S_i is a strategy set, and P_i is the payoff (utility) for the player. Let $s_i \in S_i$ and $s_{-i} \in \prod_{j \neq i} S_i$. Then this game is a supermodular game if for each $i \in I$:

1. S_i is a compact subset of $\mathbb{R}$.
2. P_i is continuous.
3. $P_i(s_i, s_{-i})$ is twice continuously differentiable with $\frac{\partial^2 P_i}{\partial s_{ih} \partial s_{ik}} \geq 0 \, \forall k \neq h$.

Lemma 1: *RS-TP is a Supermodular Game.*

Proof: We prove that RS-TP is a Supermodular Game by showing that it satisfies the above three conditions, in both levels. First, because the values of Cs follows a limited number of pricing scenarios and the values of γ are in the range [0, 1], the strategy set S_1 is a compact subset of $\mathbb{R}$. In addition, the values of S_2 are also in the range [0, 1] , thus $S_2$is a compact subset of $\mathbb{R}$. Consequently, the condition in 1 is satisfied. Besides, the payoff functions P_i and U_i are continuous with respect to the strategies of S_1 and S_2 ; thus, condition 2 is satisfied. Finally, we need to check if $\frac{\partial^2 P_i}{\partial C s_i \partial \gamma_i} \geq 0$ The twice partial differential form of the utility functions in 5.1 can be expressed as follows:

Then, we can verify that $\dfrac{\partial^2 P_i}{\partial C s_i \partial \gamma_i} \geq 0 \, \forall i \in I$, thus condition 3 is satisfied. Therefore, RS-TP is a Supermodular Game.

$$\frac{\partial^2 P_i}{\partial C s_i \partial \gamma_i} = \frac{\partial}{\partial C s_i}\left(\frac{\partial P_i}{\partial \gamma_i}\right) = \sum_{k \in I - \{i\}} \alpha_{ki} . \frac{C_i}{X_i + \sum\limits_{k \in I - \{i\}} \alpha_{ki}} \geq 0 \ ,$$

and

$$\frac{\partial^2 P_i}{\partial C s_j \partial \gamma_i} = \frac{\partial}{\partial C s_j}\left(\frac{\partial P_i}{\partial \gamma_i}\right) = 0 \ .$$

$$\frac{\partial^2 P_i}{\partial C s_i \partial \gamma_j} = \frac{\partial}{\partial C s_i}\left(\frac{\partial P_i}{\partial \gamma_j}\right) = \frac{\partial}{\partial C s_i}\left(\sum_{j \in I - \{i\}} \alpha_{ij} \cdot (p_i - C s_j) \cdot \frac{C_j}{X_j + \sum\limits_{k \in I - \{j\}} \alpha_{kj}} \right) = 0.$$

Same analysis can be done for U_i in order to verify that $\dfrac{\partial^2 U_i}{\partial \alpha_{ik} \partial \alpha_{ij}} \geq 0 \, \forall i, \, j, \, k \in I$:

$$\frac{\partial^2 U_i}{\partial^2 \alpha_{ij}} = \frac{2}{C_j} \geq 0 \ ,$$

and

$$\frac{\partial^2 U_i}{\partial \alpha_{ik} \partial \alpha_{jk}} = 0 \ .$$

Theorem 1: The Nash equilibrium exists in RS-TP

Proof: One of the properties of a Supermodular Game is that there exists a pure Nash equilibrium strategy for it [Top98], and we have shown that RS-TP is a Supermodular Game in Lemma 1. Thus, we can conclude that there exists a pure Nash equilibrium strategy for the RS-TP game. In addition, with the Best Response algorithm, we can find the best action of one player given the actions of other players, which is defined as the best response. Then the best responses of all players is the the Nash equilibrium.

5.3.4 Game Resolution

In the multi-leader follower RS-TP game, backward induction is adopted to analyse the best strategy of each player. At each level correponds an optimization problem to solve. At the lower level, each follower j first selects its strategy $\alpha_j^* = \{\alpha_{j,i}^*;\ i \neq j,\ i, j \in I\}$ and at the upper level each leader i selects its strategy Cs_i^* and γ_i^*according to the followers' decision.

5.3.4.1 Optimization Problems

Lemma 2: The NE equilibrium among followers is achieved when each follower i decides the best access selection in order to minimize its payoff, such as:

$$s.t \begin{cases} \min\limits_{\alpha_{ij}} U_i(S_1, S_2), \\ \sum\limits_{j \in I - \{i\}} \alpha_{ij} = 1 \\ \alpha_{ij} \in \{0, 1\} \end{cases} \tag{5.5}$$

As for the leaders, they will take their optimal decision for resource sharing and the transaction pricing such that to maximize their payoffs. For each leader i, the optimization problem is:

$$s.t \begin{cases} \max\limits_{Cs_i, \gamma_i} P_i(S_1, S_2^*), \\ Cs_i \geq 0 \\ \gamma_i \leq 1 \\ \gamma_i \geq 0 \end{cases} \tag{5.6}$$

The RS-TP game resolution consists of the optimization of the following bi-level problem:

$$\max_{Cs_i,\gamma_i} P_i(S_1, S_2^*), \quad s.t \begin{cases} \alpha \; solves \begin{cases} \min_{\alpha_{ij}} U_i(S_1, S_2), \\ s.t \begin{cases} \sum_{j \in I-\{i\}} \alpha_{ij} = 1 \\ \alpha_{ij} \in \{0,1\} \end{cases} \end{cases} \\ Cs_i \geq 0 \\ \gamma_i \leq 1 \\ \gamma_i \geq 0 \end{cases} \tag{5.7}$$

It is known that this kind of problem is hard to solve in this form. Therefore, we will find the Nash equilibrium at the followers level, then, we will use backward induction to solve the sequentiel decision between leaders and followers levels, and finally find the equilibrium at the leaders level.

Algorithm 5.1 RS-TP Game resolution

For the sharing factor decision,
for every player i **do**
Predict the optimal strategies of the followers α^* and the strategies γ_k^* of other partners,
Find the best γ_i^* by **maximizing P.**
end for
On a transaction event **do**
Based on the number of users **N** of the service operators,
Find the best reponse α^* for all H-ops by **minimizing U.**

5.3.4.2 Three Operator RS-TP game

In this subsection, we show how to find the equilibrium in a three player RS-TP game. Therefore, we assume that the operators of *Sys3* decided to play the RS-TP game. Thus, three players are considered, Op_1, Op_2 and Op_3. In order to solve the low level problem, we propose to use the Best Response algorithm to find the equilibrium set S_2^*. Then, using S_2^* we will find the leaders Nash equilibrium.

For illustration, we represent the extensive form of the followers game in Fig. 5.8. In this form, each node represents a player i, and each branch corresponds to its strategy $\alpha_i = (\alpha_{ij},\alpha_{ik})$ where $j \neq k$, *i.e,* for Op_1, (1, 0) corresponds to $\alpha_{12} = 1$ and $\alpha_{13} = 0$, thus Op_1 selects Op_2. In addition, d^1, $d^2 \ldots d^8$ are the outputs of the game corresponding to each stategy set S_2, such that $d^k = (U_1^k, U_2^k, U_3^k)$ and U_i^k is the resulting payoff of the operator i at output k. These payoffs are calculated from equation 5.2, and are represented in Table 5.2. Then, we find the best response of Op_2 and Op_3 in the subgames 1 & 2 depicted in Fig. 5.8. Next, we compare the payoffs of Op_1 corresponding to each

subgame solution and we choose the best response highest payoff for Op_1 (or lower U_1). Note that Op_1, Op_2 perform a simultaneous game. Thus, we will use the best response algorithm to find the Nash equilibrium for each subgame. Then we compare the utilities of Op_1in each subgame output d, and we choose the solution that minimizes U_1. Algorithm 5.2 describes how to find the low level equilibrium.

Algorithm 5.2 Finding low level Nash equilibrium

set i=0;
initialise strategy profile i of Op_2 and Op_3;
while strategies changing **do**
minimize U_2 and get α_2; given α_3^i
minimize U_3 and get α_3; given α_2^i
update i's strategy profile;
i=i+1;
end
given the i's strategy profile, **minimize** U_1 and get α_1^i
define the equilibrium as $S_2^* = (\alpha^i{}_1, \alpha^i{}_2, \alpha_3^i)$

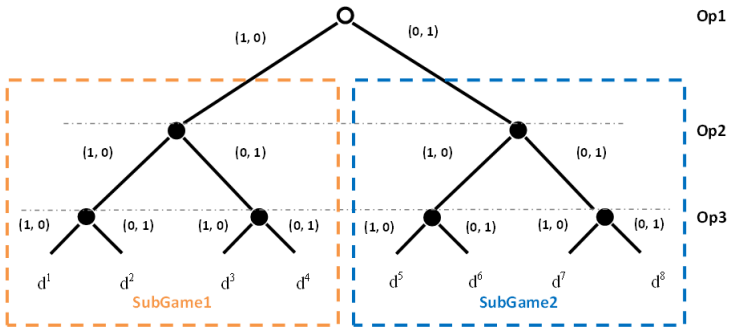


Figure 5.8: Extensive form representation of the low level (followers) game and subgames 1&2

Table 5.2: Game output payoffs

Game Output	$U_1(\alpha_1, \alpha_2, \alpha_3)$	$U_2(\alpha_1, \alpha_2, \alpha_3)$	$U_3(\alpha_1, \alpha_2, \alpha_3)$
d^1	$\frac{N_2+1}{C_2}$	$\frac{N_1+2}{C_1}$	$\frac{N_1+2}{C_1}$
d^2	$\frac{N_2+2}{C_2}$	$\frac{N_1+1}{C_1}$	$\frac{N_2+2}{C_2}$
d^3	$\frac{N_2+1}{C_2}$	$\frac{N_3+1}{C_3}$	$\frac{N_1+1}{C_1}$
d^4	$\frac{N_2+2}{C_2}$	$\frac{N_3+1}{C_3}$	$\frac{N_2+2}{C_2}$
d^5	$\frac{N_3+1}{C_3}$	$\frac{N_1+2}{C_1}$	$\frac{N_1+2}{C_1}$
d^6	$\frac{N_3+1}{C_3}$	$\frac{N_1+1}{C_1}$	$\frac{N_2+1}{C_2}$
d^7	$\frac{N_3+2}{C_3}$	$\frac{N_3+2}{C_3}$	$\frac{N_1+1}{C_1}$
d^8	$\frac{N_3+2}{C_3}$	$\frac{N_3+2}{C_3}$	$\frac{N_2+1}{C_2}$

Table 5.3: Partners network states

Operator	K	X	N	C	p
Op1	4	0	4	1700	0.9
Op2	8	3	11	11000	0.1
Op3	8	3	11	5500	0.2

Applying the parameters in Table 5.3, we obtain the optimal strategies ${\alpha^*}_{12} = 1$, ${\alpha^*}_{23} = 1$ and $\alpha^*_{32} = 1$, and the output of the low level game is d_4. It means that, Op_1 and Op_3 select Op_2 for the service of their clients, and Op_2 selects Op_3. Consequently, from equation 5.6 , we can determine the leaders payoffs P_1, P_2 and P_3 as follows:

$$\begin{cases} P_1 = (p_1 - Cs_2) \cdot \dfrac{\gamma_2 \cdot C_2}{X_2 + 2} = 1980.\gamma_2 - 2200.\gamma_2 \cdot Cs_2 \\ P_2 = (p_2 - Cs_3) \cdot \dfrac{\gamma_3 \cdot C_3}{X_3 + 1} + 2.Cs_2 \cdot \frac{\gamma_2 \cdot C_2}{X_2 + 2} \\ = 137,5.\gamma_3 - 1375.\gamma_3 \cdot Cs_3 + 4400.\gamma_2 \cdot Cs_2 \\ P_3 = (p_3 - Cs_2) \cdot \dfrac{\gamma_2 \cdot C_2}{X_2 + 2} + Cs_3 \cdot \frac{\gamma_3 \cdot C_3}{X_3 + 1} \\ = 440.\gamma_2 - 2200.\gamma_2 \cdot Cs_2 + 1375.\gamma_3 \cdot Cs_3 \end{cases} \tag{5.8}$$

Note that, in this case, the leaders' payoffs depends only on the decision of Op_2 and Op_3. Therefore, the RS-TP game will take place only between these two operators. Op_2 and Op_3 will choose the best γ and Cs that maximize their profits. We will follow the algorithm 5.3 to find the Nash equilibrium in the leaders level of the RS-TP game. The output of the leaders game gives $S_1^* = ((1, 1), (1, 1))$.

Algorithm 5.3 Finding upper level Nash equilibrium

set i=0;
initialise strategy profile i of Op_2 and Op_3;
while strategies changing **do**
given (γ_2^i, Cs_2^i), **maximize** P_3 and get (γ_3, Cs_3);
given (γ_3, Cs_3), **maximize** P_2 and get (γ_2, Cs_2);
update i's strategy profile;
i=i+1;
end
define the equilibrium as $S_1^* = ((\gamma_2, Cs_2), (\gamma_3, Cs_3))$

5.4 Conclusion

In this chapter, we studied the a hybrid access mode in a three partners sharing system. We showed that sharing a restricted amount of resource guarantee clients satisfaction for the operators sharing the highest capacity. In addition, when the partners increase the

sharing factor they guarantee higher profits, using the suitable transaction cost pricing scenario. Further, we formulated a two level sequentiel game, RS-TP, in which the operators decide the sharing factor and the transaction cost pricing scenario to adopt, in order to maximize their profits. We demonstrated the existence of Equilibria, and we gave the principal resolution lines. Finally, we introduced an exemple of a three operators sharing system and we an equilibrium point for one system instance. Results showed that, when considering the profits as the operators payoff, a sharing factor of 100% is obtained as the best decision, *i.e,* sharing the maximum resource maximizes the profits of the sharing partners. But this strategy will affect the blocking rates of the operator sharing the highest capacity.

Chapter 6

Conclusion and Future Directions

This chapter concludes this thesis report. We summarize the main contributions, and give the future research directions that stem from this work.

6.1 Thesis Contributions

This thesis has investigated radio access selection and pricing in multi-operator sharing networks. Our work is in the context of heterogeneous wireless networks, where various RATs covering the same region and managed by different operators are being integrated in a shared RAN. One of the main motivations behind RAN sharing is to reduce the total cost of network deployment and management and increase revenues. Another motivation is to reduce the network deployment period and accelerate the rollout of new technology, in order to handle the rapid growth of mobile broadband demand. A inter-operators sharing agreement must address radio access selection process, devoted to decide which operator to connect to. Access selection decision is a key for common radio resource management in a multi-operator networks. It serves to improve network performance and user satisfaction. Moreover, a sharing agreement includes financial conciliation for the service cost between partners, which represents the cooperation fees between them. Furthermore, the inter-operator agreement determines how to share resource, and the adopted access mode. Indeed, determining the amount of shared resources with partners affects the operators' benefits from cooperation and allows to maintain own network performance.

First, we introduced our selection decision algorithm in a multi-operator environment, NP-BPA. It is based on a multi-criteria cost function, which groups the different parameters that enable a satisfying selection decision for operators and users at the same time. In this decision process, the home operator of the transferred user is the principal player; it triggers and performs the selection applying its own strategy. The latter is expressed explicitly in our cost function using two specified coefficients. Besides, we showed the efficiency of our selection algorithm in different environments considering different numbers

of partners. The performance of NP-BPA algorithm was compared to MADM methods, precisely SAW and NPH, in a three operators environment. NP-BPA showed better results for the blocking rates and global achieved profits. Our algorithm could grab the simplicity and speed of MADM methods, prevent overloading situations for the service operator, by distributing transferred users in an efficient manner, and thus improve the profits for all cooperating partners. Results verified the benefits of cooperation between operators, in terms of blocking rates and achieved profits, and showed how the choice of the partner affects the network performance improvement and the profit gains. Moreover, the operator sharing the highest capacity, serves high numbers of guest users, which affects negatively its clients acceptance. One solution resides in choosing a suitable transaction cost able to control the guests flow and guarantee good revenues. And a second solution is to limit the amount of shared capacity in order to guarantee the priority for the operator clients in a hybrid access mode.

For this objective, we proposed three pricing scenarios that determine the transaction cost of an operator as a function of its service price or the service prices of the other partners. This transaction cost is to be paid by the home operator of the transferred user, and the latter pays the service price to its home operator; the transaction is transparent to the user. The first pricing scenario, ACAG (As Client As Guest) aims to set the transaction cost of an operator equal to its service price. The second pricing scenario MIWC (Max In When Cooperating) consists that all partners agree to have a transaction cost equal to the highest service price announced in the system. And the third pricing scenario MCWC (Min Cost When Cooperating) consists that scenario all partners agree to have a transaction cost equal to the lowest service price announced in the system. We studied the profitability of these pricing scenarios and we comapred them to different price sharing scenarios, using two system models: In the first system, BSBC, the operators set the same pricing scenario but share different capacities. In the second system, BSBP, the operators share the same capacity but set different service prices. In Results showed that the best pricing scenario for an operator depends on its shared capacity and the service price it sets. Besides, one pricing scenario may maximize the profits of one operator but not of the others. Hence, to decide the best pricing scenario to adopt in the sharing system, a two stage Stackelberg game, TPA (Transaction Pricing and Access Selection) game, is formulated. In this game, the operators are the players; the service operators are the leaders and the home operator of a transferred user is a follower. Two cases were studied: the first one where all operators adopt the same pricing scenario. In this case we found the U-TPA (Uniform Transaction Pricing and Access Selection) equilibrium. And, the second case where each operator adopts its own pricing scenario. In this case we found the F-TPA (Free Transaction Pricing and Access Selection) equilibrium. In both cases the equilibrium scenario is MIWC. In fact, in the system where the partners share different capacities and set different service price, MIWC guarantees the best profit sharing among all partners.

Finally, we considered a three operator sharing system with hybrid access mode. In this system partners decided to share a restricted amount of their capacity. We showed how the sharing factor affects the blocking rates and affect the global profits. Further, the achieved profit does not depend only on the sharing factor, but also on the adopted pricing scenario. Therefore an economic framework based on game theoretical analysis was proposed. It models the interaction between the sharing system operators for resource sharing and pricing, in addition to the access selection. A sequential game was formulated, RS-TP game (Resource Sharing and Transaction Pricing), where the players are the operators. In the first stage, the sharing partners decide the proportion of resources they will share and the transaction pricing scenario in order to maximize their own profits. In the second stage, the home operator of a transferred user selects the suitable service operator. A bi-level multiobjective optimization problem was simplified and solved and equilibria were found.

6.2 Futur Directions

Heterogeneous Cloud Radio Access Networks (H-CRAN) exploit Heterogeneous Networks (HetNet) and Cloud Radio Access Networks (C-RAN) concepts for next generation cellular networks. The heterogeneity of macro and small cells from HetNet, enables cellular networks to achieve a higher spectral efficiency. Meanwhile, concepts from C-RAN involving baseband units and remote radio heads enable H-CRAN to insert a centralized point of processing for cellular networks, reducing CAPEX and OPEX.

Resource sharing in H-CRAN can be divided in three levels: Spectrum sharing that may be performed through different allocation units, e.g., channels used on IEEE 802.11.* , Resource Blocks from LTE frames and unused portions of the spectrum, called white spaces. Infrastructure sharing is achieved through the virtualization of physical entities by decoupling their functionality from the hardware, thus the infrastructure workload is computed at the Baseband Processing Units (BBU), where resource availability as well as overloading of physical entities becomes easier to assess. Network sharing, where our proposal can be implemented, consists of abstracting resources of spectrum and infrastructure into sharing entities, network slices, and logical links. It focuses on managing available resources, regardless of their physical representations, e.g., spectrum and infrastructure. At this level, the BBU can be responsible for processing the entire network configuration, orchestration, signal processing, and accounting for policies/QoS requirements [MKGM+15].

In this context operator resources from macro and small cells can be efficiently shared by having their workload optimally processed at shared BBU pools through Cloud-Computing based Cooperative Radio Resource Management (CC-CRRM). The BBU pool can easily identify a macro cell as overloaded, directing users to handover to a shared underutilized small cell from another operator without the need for additional steps to

process the inter-operator handover. Therefore, our selection decision algorithm can be updated in order to take into account new parameters including the spectrum efficiency, the service operator load, the interference and the energy consumption. These parameters reflect the ability of the service operator to cooperate.

In addition, considering the access technology of the partners of a sharing system, it would be interesting to evaluate the cost of serving a guest user in function of the the physical resource (e.g Resource Blocks in LTE) and the energy consumption. Moreover, with a hybrid access mode, the sharing factor determines the amount of physical shared resources, thus the total cost of serving guest users, which helps to deduce the transaction cost of each operator. This adds a new pricing scenario to our proposition for the inter-operator transaction cost. Such pricing scenario simplifies the economic framework proposed for resource sharing and service pricing, and the partners' decision will be reduced to the resource sharing factor.

List of publications

1. Farhat, S.; Samhat, A. E.; Lahoud, S. & Cousin, B., " *Comparison between access selection algorithms in multi-operator wireless networks*", International Conference on Applied Research in Computer Science and Engineering (ICAR), 2015.

2. Farhat, S.; Samhat, A. E.; Lahoud, S. & Cousin, B., "*Pricing Strategies in Multi-Operator Heterogeneous Wireless Networks*", NTMS'15 : The Seven IFIP International Conference on New Technologies, Mobility and Security, 2015.

3. Farhat, S.; Chahine, Z.; Samhat, A. E.; Lahoud, S. & Cousin, B., *"Access selection and joint pricing in multi-operator wireless networks: A Stackelberg game*", Fifth International Conference on Digital Information and Communication Technology and its Applications (DICTAP), 2015.

4. Farhat, S.; Samhat, A.; Lahoud, S. & Cousin, B., "*Best operator policy in a heterogeneous wireless network*", Third International Conference on e-Technologies and Networks for Development (ICeND), 2014.

5. Farhat, S.; Samhat, A. E. & Lahoud, S., " *Hybrid decision algorithm for access selection in multi-operator networks",* IEEE Wireless Communications and Networking Conference (WCNC), 2014.

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