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Radio Access Network Sharing in 5G: Strategies and Benefits

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Abstract In a shared radio access network, 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 the home operator is unable to serve its user, and there is more than one available service operator, a selection decision must be made. The decision must consider the satisfaction of three main agents: the user, his home operator and the service operator. This paper presents a strategic algorithm for the access selection decision in a multi-operator wireless network. It is based on a cost function that combines the requirements of the user, its home operator profit and the offered QoS of the service operator. This cost function takes into account the operators' strategies for cooperation. This work focuses on the service operator strategy and proposes two strategies: a pricing strategy that consists of increasing the service cost, and a sharing strategy that consists of limiting the amount of shared resources. Simulation results prove the efficiency of the proposed algorithm and show how sharing between operators brings benefits in terms of user acceptance and profits as well. In addition, results show that the service operator strategy affects the access selection decision and the cooperation benefits; a pricing strategy can guarantee high profits for the service operator and can improve its client acceptance.

Keywords RAN sharing · Radio access selection · Cost function · Resource sharing · Service cost · Operator strategy

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1 Introduction

5G mobile technology promises innovation for entire mobile industry [1–3]. 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, Software Defined Networks (SDN) and Network Function Virtualization (NFV) technologies.

For operators, time and cost are crucial. Therefore, a rational decision has to be done in order to hold on with the mobile market evolution. And, since incomes are not growing with the same rate as the traffic, 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 [4–6]. 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 [6]. 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) [7].

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; femtocells and picocells are created by Radio Remote Heads (RRHs) instead of low power base stations (BSs) and access points, and the infrastructure workload is computed at the Base Band Processing Units (BBU), which can be shared among different operators in the Cloud [8–10].

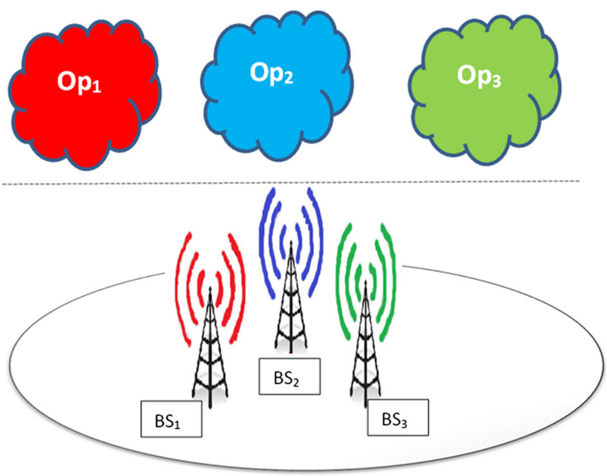


Fig. 1 Multi-operator environment

In this work, a sharing system is considered where multiple operators share their radio access in a multi-operator environment Fig. 1. In such system, mobile users can access BS of their home operator or the BS of another operator of the sharing system. It is assumed that 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 transfers the considered user to another operator, in including an access selection decision in order to choose the best operator for service. And, it is supposed 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 service cost as cooperation fees for the selected service operator. This transaction is seamless to the user. Operators' cooperation is unavoidable in order to improve the global system performance and increase operators' profits. Moreover, such cooperation helps to avoid the underutilization of radio resources when traffic level is lower than planned, and QoS degradation when the traffic is higher than expected.

This paper investigates the strategies that a service operator may adopt in a sharing system, in order to optimize the cooperation benefits in terms of client acceptance and profits. The S-AS (Strategic Access Selection) algorithm for the access selection decision is introduced. It is based on the NP-BPA function, previously proposed and analyzed in [5, 11, 12]. It ensures the mobile user and its home operator satisfaction by combining the requirements of the mobile user's application, the offered QoS from the radio access networks and the resulting profit from the user transfer. The S-AS algorithm takes into account the service operator strategy. It aims to prevent overloading the network with guest users while maximizing its revenue from sharing. Two strategies are proposed, the first consists of controlling the announced service cost and the second consists of determining the amount of shared resources with other operators in the system.

The main contributions of this paper for multi-operator sharing networks include:

1. The application of a strategic algorithm S-AS for the access selection in multi-operator network. It is achieved in two scenarios using: the open access mode, where the operators share all their resources with guest users, and the hybrid access mode, where the operators share only a percentage of their resources.
2. The proposition of two strategies for the service operator in order to maintain sharing benefits and network performance. The first strategy, referred to the pricing strategy, consists of increasing the service cost. And the second, referred to the sharing strategy, consists of reducing the amount of shared resources.
3. The comparison of the pricing and sharing strategy in terms of the network performance and profits, to show their effect on the cooperation benefits for all sharing operators.

The remainder of the paper is organized as follows: Sect. 2 presents some existing work related to radio access selection algorithms. Section 3 describes the decision algorithm and highlights the expression of the operator's strategies. Simulation environment and results are presented in Sect. 4. Finally, Sect. 5 concludes the paper.

2 Background and Related Works

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 [13]. Access selection tools include: utility and cost function used in [14–17], Multiple Attribute Decision Making (MADM) methods in [15, 18–24], Fuzzy Logic in [24–26], Markov Chain in [27, 28] and Game Theory in [29–34]. 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 includes the bandwidth, BER, the delay, the jitter, the price and latency, used with Linear or sigmoidal utility functions.

In [26] 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 [24], 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 [22], 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 example of combining GRA with AHP-based weighting is presented in [13].

NPH approach, introduced in [15], 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 [32], authors use AHP and GRA in order to construct the payoff of requests and achieve network selection using multi-round game.

In [23], 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 [35], to ensure load balancing, while minimizing the costs of resource underutilization and demand rejection.

In a multi-operator heterogeneous network, a new "flex service" paradigm was introduced in [36]. It allows a mobile user subscribed to "Flex service" to dynamically access base stations (BSs) of different providers. Authors present two modeling framework at both macroscopic and microscopic levels. At a microscopic level, a flex user accesses dynamically base station of different providers based on various criteria, such as profile, network conditions and offered prices. In this work, a similar multi-operator environment is envisaged, where a user can access the base station of a different provider. However, the 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. At a macroscopic level, 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 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 [31], 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.

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 [37]. 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 [38], the interaction between wireless operators, in a multi-operator sharing network, is modeled using a multi-leader-follower (Stackelberg) game. Cooperating service operators announce their service 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.

Another approach for Joint Radio Resource Management (JRRM) is introduced in [39, 40]. 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 [13], it shows the strong and weak points of each techniques. The comparison results are resumed in Table 1, it shows the implementation simplicity of MADM and its high precision, in addition to the high precision of game theory and its ability to fulfill equilibrium between multiple entities.

In [5, 12], the advantages of MADM techniques, especially the simplicity of SAW and NPH, are exploited to develop a hybrid decision algorithm, NP-BPA (Nearest Performance and Best Profit Access Selection Algorithm), for the access selection in a multi-operator network environment. This algorithm seeks to minimize the distance between the user application requirements and the offered QoS and to minimize the user transfer profit, in the same time. SAW scoring is used in two levels. In the first level, the user and available

Table 1 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 entities	Consecutive decisions/rank aggregation/priority evaluation
Decision speed	Fast	Fast	Fast	Medium	Medium
Implementation complexity	Simple	Simple	Simple	Complex	Medium
Precision	Medium	High	Medium	High	High

operators score are specified, than NPH is applied to form the distance between the user application requirements and the offered QoS. In the second level, the QoS distance and the resulting profit from the user transfer are weighted and added in a cost function. Simulation results showed the efficiency of the proposed decision algorithm in a three operators sharing network. Moreover, the comparison of NP-BPA algorithm with SAW and NPH was made in [11], simulation results showed that the proposed decision algorithm guarantees the lowest blocking probability for all operators, it prevents overloading operator's with high numbers of guest users which affect own clients acceptance. In addition, it improves global achieved profits for all cooperating operators.

In this paper, the approach differs from previous works by considering the open access mode, where the operators share all their resources with guest users and the hybrid access mode, where the operators share only a percentage of their resources. In the hybrid access mode scenario, the sharing operators decide the sharing factor γ. It represents the percentage of capacity to share with guest users coming from another operator. Besides, for the access selection, the decision cost function is reformulated into S-AS, in order to take into account the service operator strategies. Further, this work focuses on the satisfaction of the service operator, having the highest capacity. It seeks the best strategy to adopt in order to maximize the benefits from sharing. This operator can decide to increase the service cost or decrease the amount of shared resources independently of other operators, in order to maintain better performance and higher profits.

3 Access Selection Algorithm

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. 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 triggered 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 transferred to another cooperating operator to avoid his rejection. The system logic is represented in Fig. 2.

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 example, when the selection decision seeks the user satisfaction in terms of QoS, parameters as the throughput, delay, BER must be considered to satisfy the user application requirements. In the considered sharing model, the offered bandwidth will be taken as the QoS decision parameter.

In addition, when the user has limited budget for the service access, the service price of the new *S-op* has to be considered. Besides, the user preferences are difficult to specify and depend strongly on the willingness of the user to pay. Moreover, the access selection decision must consider the operator satisfaction, precisely the *H-op* of the transferred user. In fact, in the considered model the user does not pay any additional fees for the service, its payment goes to its *H-op* respecting the contract between them. The H-op has to pay the

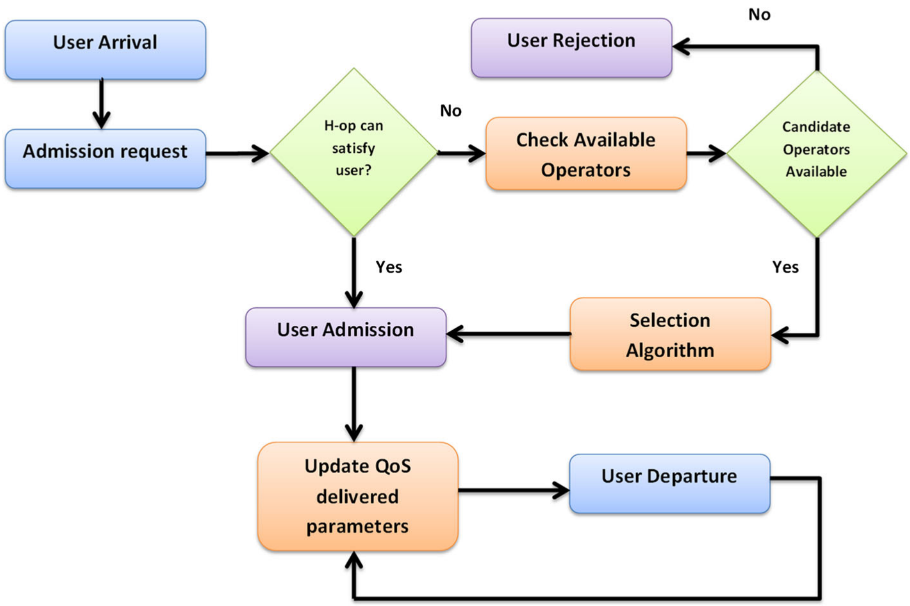


Fig. 2 System logic

cooperation fees, *i.e,* the service cost c^t, to the service operator. Hence, the *H-op* looks to minimize this cost, and to apply its own strategy for the user transfer. The strategy of an operator is defined 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 the cost function using two coefficients for the degree of importance of the user satisfaction and of the operator service costs.

Consequently, when a transaction event is triggered, the offered bandwidth and c^t 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, and then the selection decision is made. Figure 3 resumes the required parameters for the selection decision algorithm.

3.1 Decision Cost Function

The selection candidates are the partners capable of offering the best QoS for the user, with the highest profit. In the following subsections, the SAW scoring and NPH approach for the selection decision are briefly described, then the adopted selection cost function is introduced.

3.1.1 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 [23]. The access network having the highest score will be selected for the user service. In [15, 22], four QoS parameters are considered: 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 a multi-operator environment the access network is represented by its operator. Therefore,

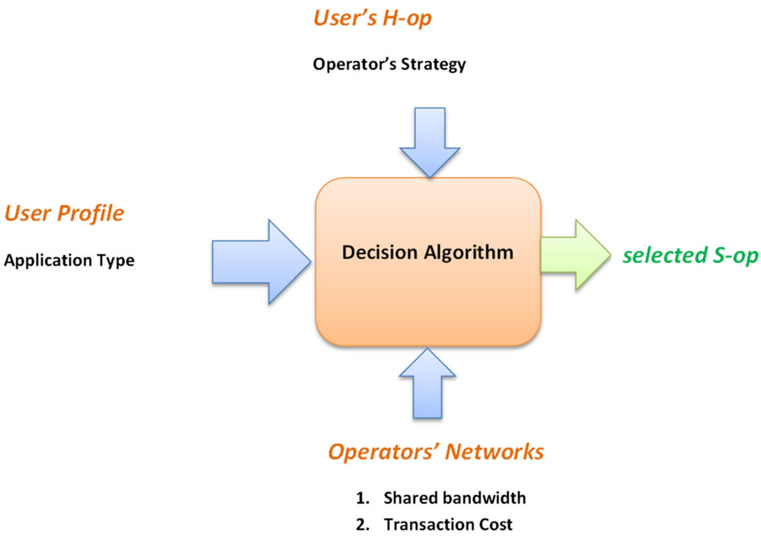


Fig. 3 Decision parameters

using the QoS parameters mentioned above, the score of the ith service operator may be calculated as follows:

$$S_i^{SAW} = w_J \cdot J_{M_i} + w_D \cdot D_{M_i} + w_{BW} \cdot BW_{R_i} + w_{BER} \cdot BER_{M_i} \quad (1)$$

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.

3.1.2 Nearest Performance Handover (NPH)

The NPH approach is initially proposed in a single operator context [15] and can be used in a 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 the considered model, a proposition was made in [11] 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:

$$Su = \eta \cdot (w_J \cdot J_{req} + w_D \cdot D_{req} + w_{BW} \cdot BW_{req} + w_{BER} \cdot BER_{req}) + \theta \cdot p \quad (2)$$

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 ith service operator, $S_i^{\prime SAW}$, is calculated as follows:

$$S_i^{\prime SAW} = \eta \cdot (w_J \cdot J_{M_i} + w_D \cdot D_{M_i} + w_{BW} \cdot BW_{R_i} + w_{BER} \cdot BER_{M_i}) + \theta \cdot p_i \qquad (3)$$

where p_i is the service price of the ith operator set for its clients. Finally, the score of the ith service operator is calculated as follows:

$$S_i^{NPH} = |S_u - S_i^{\prime SAW}| \qquad (4)$$

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

3.1.3 Strategic Access Selection Algorithm (S-AS)

The proposed algorithm considers the H-op happiness during the selection decision, thus, the service cost c_i^t will be taken as a decision parameters. Besides, considering the second strategy of the *S-op,* the remaining of the shared bandwidth sBW_{Ri} is considered as the offered QoS parameters. In fact, $sBW_i = \gamma_i \cdot BW_i$ where BW_i is the total capacity of $S\text{-}op_i$, γ_i is the resource sharing factor and sBW_i is the total bandwidth shared with other operators. Hence, $\left[c_i^t, \gamma_i\right]$ represents the strategy of $S\text{-}op_i$. Based on SAW scoring and NPH distance, the S_i^{S-AS} score of the ith *S-op*, forming the cost function for the user transfer is calculated as follows:

$$S_i^{S-AS} = g_u \cdot |BW_{req} - sBW_{R_i}| - g_o \cdot (p - c_i^t) \qquad (5)$$

where g_o and g_u are the sensitivity weights for the service cost and QoS, respectively, and $\frac{g_o}{g_u}$ quatifies the *H-op* policy.

The selected *S-op* is the one having the lowest S_i^{S-AS}, thus minimizing the service cost and maximizing the offered QoS parameters.

4 Simulations and Results

The performance evaluation of the proposed selection algorithm S-SA is concerned with the global performance of the sharing system, the network performance for each operator and their profits. The global performance is quantified by the global blocking rates which are calculated as the ratio of the total number of blocked users over the total number of arrivals to the sharing system. Although, the network performance is quantified by the blocking rates for each operator calculated as the ratio of the blocked clients over the client arrivals for each operator. And, the profits of an operator is calculated as the total income from served clients, added to the total revenue from served guests minus the total service cost resulting from the user transfer to other operators.

Consider the system formed by three operators, where each operator manages a single radio access network. The performance analysis starts by the open access mode scenario, where all operators adopt the same strategy $\left[c_i^t, \gamma_i\right] = [p_i, 1]\, \forall i$, *i.e,* all operators set a service cost equal to their service price p_i, and they share all their capacity. This scenario shows the efficiency of the proposed selection algorithm and the benefits of sharing between operators in terms of user acceptance and profits. Next, the analysis continues with the strategic sharing mode: first the pricing strategy is used and second the sharing strategy is applied. Finally, the pricing and the sharing strategies are compared focusing on the advantages of each strategy for the operator with the highest capacity.

The arrival and departure of users are modeled as a Poisson Process with mean arrival interval $\frac{1}{\lambda}$ s. Once connected, the user will stay in the system for a service time, assumed to follow an exponential distribution of mean $\frac{1}{\mu}$; let $\frac{1}{\mu} = 4$ min as a typical value used in [22] . 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, and the results are given with a confidence interval of 95%.

4.1 Open Access Mode Analysis

Consider the sharing system formed by the three operators Op_1, Op_2 and Op_3. All operators agree to share all their capacity in an open access mode, and use the selection algorithm, S-AS. The simulation of this scenario is made using the values 1700, 11,000, 5500 kB/s for the capacities of Op_1, Op_2 and Op_3, respectively. For the service price p, the following values are used: $p_1 = 0.9$, $p_2 = 0.1$ and $p_3 = 0.2$ unit/kB, for Op_1, Op_2 and Op_3, respectively. In addition, the values $\frac{1}{\lambda} = 2.7, 3, 3.33, 4, 5, 7, 9, 12, 24$ s are used for the mean inter-arrival interval. The performance analysis in terms of blocking rates and profits improvement is made for a value of $\frac{g_u}{g_o} = 1$ in Eq. 5, i.e that when an operator transfers a client to another service operator, the service cost and QoS will have the same importance. In this scenario, with open access mode, the performance results can be compared to the previously obtained results using NP-BPA as the selection algorithm.

4.1.1 GLobal Performance

The global performance of the system is studied in terms of global blocking rates. Figure 4 presents the global blocking rates of the system in function of the arrival rates λ, using

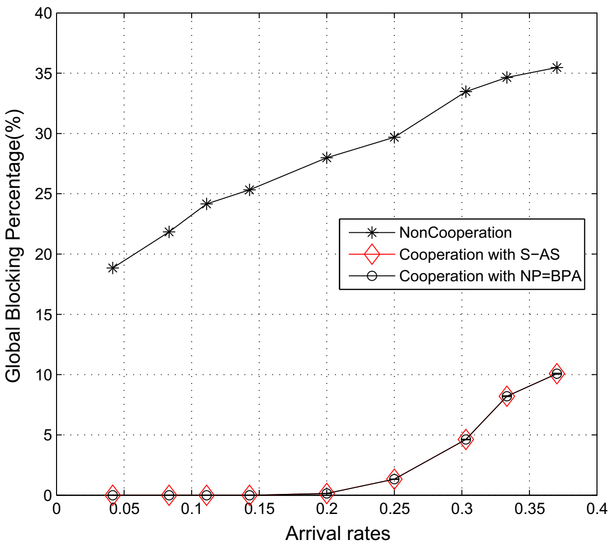


Fig. 4 Global blocking rates in the open access mode

S-AS and NP-BPA. First, notice that the global blocking rates obtained with S-AS with open access mode are identical to those obtained with NP-BPA. 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.

4.1.2 Network Performance

Figure 5a–c show a comparison between the blocking rates, without cooperation, and with cooperation using S-AS and NP-BPA as a selection algorithms, for Op_1, Op_2 and Op_3, respectively. First, notice that the blocking rates obtained with S-AS are identical to those obtained with NP-BPA for all sharing operators. In fact, Op_1, sharing the lowest capacity, is taking the largest benefit from this cooperation. Its blocking probability is reduced up to 78% (Fig. 5a), clients are transferred to Op_2 and Op_3 instead of being blocked. In addition, Op_3 sharing a medium capacity, has reduced also its blocking percentage after cooperation (Fig. 5c). And Op_2, sharing the highest capacity, could maintain the blocking percentage below 0.3% at low arrival rates. But at high arrival rates, this operator was penalized by a high number of guest users, which increased its blocking rates.

4.1.3 Operators' Profit Improvement

Figure 6a–c 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 using S-AS and NP-BPA and those without cooperation, one can see that the operators of the sharing system could realize important profit gains through cooperation. The proposed selection algorithms could guarantee the satisfaction of the operators transferring their users by selecting the S-op with lower costs. In adddition, the profit achieved using S-AS are identical to those achieved with NP-BPA.

In fact, the increase of the users' acceptance after cooperation, brought more incomes for Op_1; clients are transferred to another serving operator instead of being blocked and losing their payments (Fig. 6a). Op_3 also benefits from profit improvement (Fig. 6c). 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 2, has revealed that more than 35 % of the served users are guest users. This did not improve the profits of Op_2 since its service cost is set equal to its price ($\left[c_2^t, \gamma_2\right] = [p_2, 1]$), but the impact was clear on the client acceptance.

4.2 Strategic Sharing Mode Analysis

Previous results showed that Op_2, sharing the highest capacity, is penalized with an increase of the blocking rates at high arrival rates. In fact, at high arrival rates, the served guest percentages are very high affecting Op_2's client acceptance. In this subsection, the pricing and sharing strategies are applied in order to improve the blocking rates of Op_2 and improve its profit. First, the pricing strategy is used, and it is proposed that Op_2 increases its service cost c^t, while sharing all its capacity. It will affect the number of guest users,

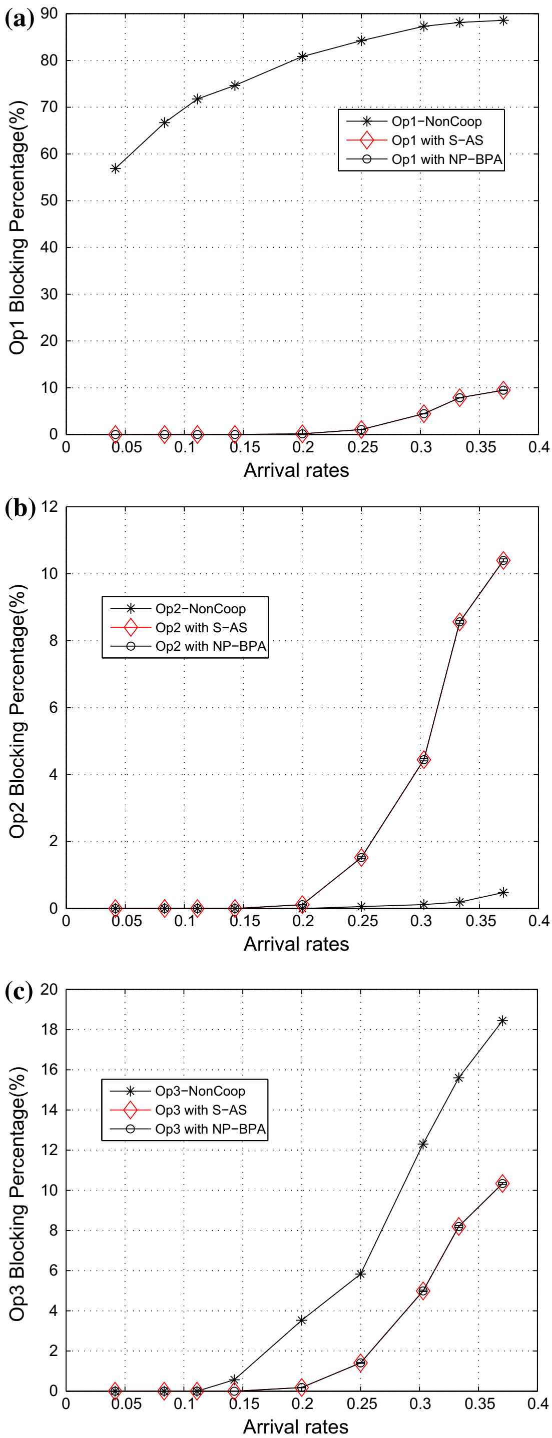


Fig. 5 Operators' network blocking rates in the open access mode. **a** Op_1's blocking rates in the open access mode. **b** Op_2's blocking rates in the open access mode. **c** Op_3's blocking rates in the open access mode

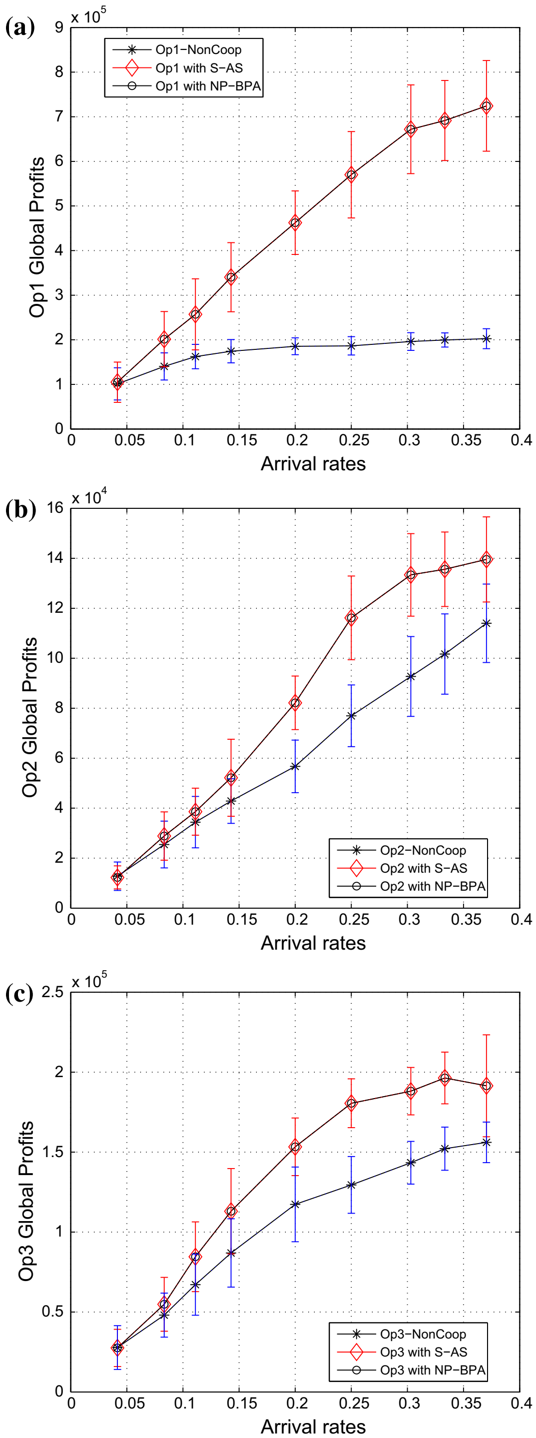


Fig. 6 Operators' Global Achieved Profits in the open access mode. **a** Op_1's global profits in the open access mode. **b** Op_2's global profits in the open access mode, **c** Op_3's global profits in the open access mode

Table 2 Op2's Serving rates (%)

Serving rates (%)								
Arrival rates λ	0.08	0.11	0.14	0.2	0.25	0.3	0.33	0.37
Guest percentages	35	35	37	43	45	48	48	50

since the service cost is a parameter in the selection decision cost function in Eq. 5. Then, the sharing strategy is used, and Op_2 reduces the amount of shared capacity, while keeping a service cost equal to its price ${c_2}^t = p_2$.

4.2.1 Application of the Pricing Strategy

Consider the sharing system formed by the three operators Op_1, Op_2 and Op_3. These operators share all their capacities and set different service prices $p_1 = 0.9$, $p_2 = 0.1$ and $p_3 = 0.2$ unit/kB, respectively. Using the service cost pricing scenarios proposed in [41], the following scenarios will be compared:

Scenario 1: The operators, Op_1, Op_2 and Op_3, adopt ACAG (As Client As Guests) as a pricing scenario [41], such that each operator sets a service cost equal to its service price. Accordingly, the strategy vectors are $\left[c_1^t, \gamma_1\right] = [0.9,\ 1]$, $\left[c_2^t, \gamma_2\right] = [0.1,\ 1]$ and $\left[c_3^t, \gamma_3\right] = [0.2,\ 1]$ for Op_1, Op_2 and Op_3, respectively. This scenario will be referred to the open access mode in the rest of the paper.

Scenario 2: Op_2 chooses to set the highest service cost in the system, while Op_1 and Op_3 adopt ACAG, with strategy vectors, $\left[c_1^t, \gamma_1\right] = [0.9,\ 1]$ and $\left[c_3^t, \gamma_3\right] = [0.2,\ 1]$, respectively. Indeed, Op_2 adopts MIWC (Max In When Cooperating) as a pricing scenario [41], and it sets a service cost equal to the highest service price in the group, such as $\left[c_2^t, \gamma_2\right] = [0.9,\ 1]$.

Sceanrio 3: All operators adopt MIWC and set their service cost to the highest service price in the group such as , $\left[c_1^t, \gamma_1\right] = [0.9,\ 1]$, $\left[c_2^t, \gamma_2\right] = [0.9,\ 1]$ and $\left[c_3^t, \gamma_3\right] = [0.9,\ 1]$, for Op_1, Op_2 and Op_3 respectively.

4.2.1.1 Blocking rate variation Figure 7a–c show the blocking rates of Op_1, Op_2 and Op_3 respectively, for the different scenarios and the non cooperation case. For all considered operators, the best values of the blocking rates are achieved with scenario 2 where Op_2 adopts MIWC and sets its service cost to the highest service price in the group, while Op_1 and Op_3 adopt ACAG by setting their service cost to their service price p. In other words, the best pricing strategy for Op_2 is to set a high service cost, at least equal to the highest service price adopted in the sharing system. This strategy guarantee the lowest blocking rates for Op_2 and all other operators. Hence, comparing to the open access mode in scenario1, adopting a pricing strategy have improved the client acceptance of the operator sharing the highest capacity and all other sharing operators.

4.2.1.2 Profit variation Figure 8a–c show the global achieved profits, for Op_1, Op_2 and Op_3 respectively, for the different scenarios and the non cooperation case. Op_2 and Op_3 achieve the highest profits when Op_2 adopts the strategy of scenario 2. But, for Op_1 the

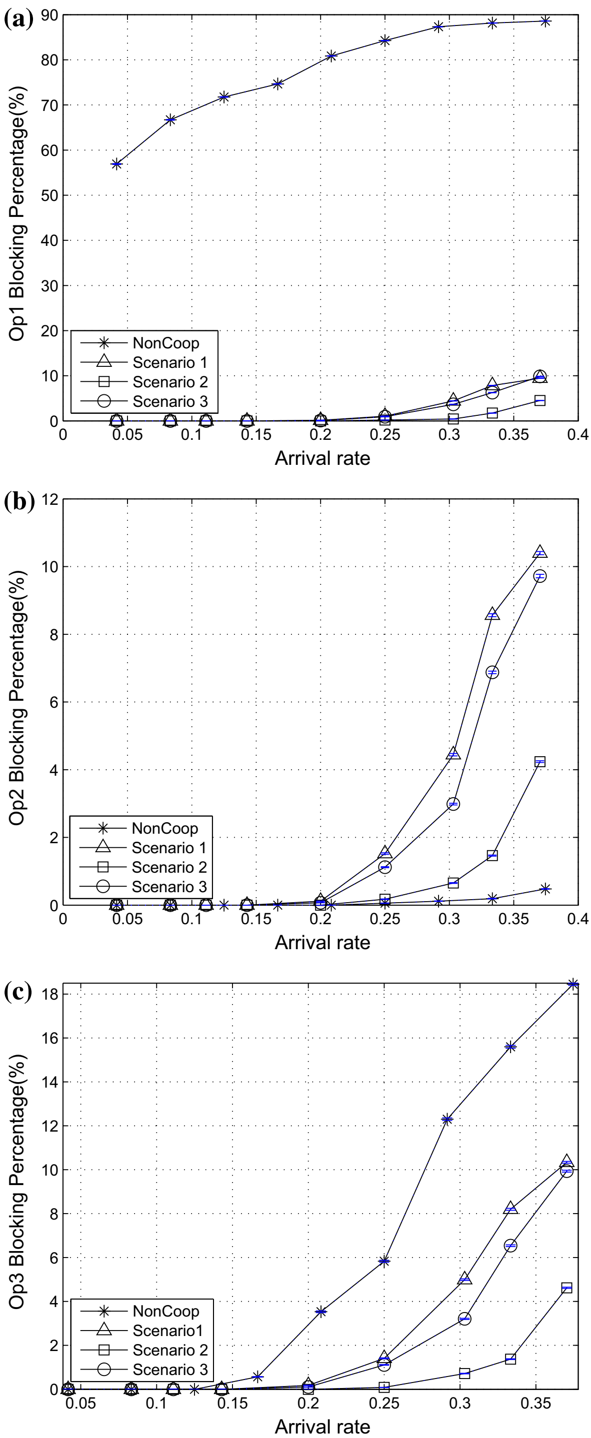
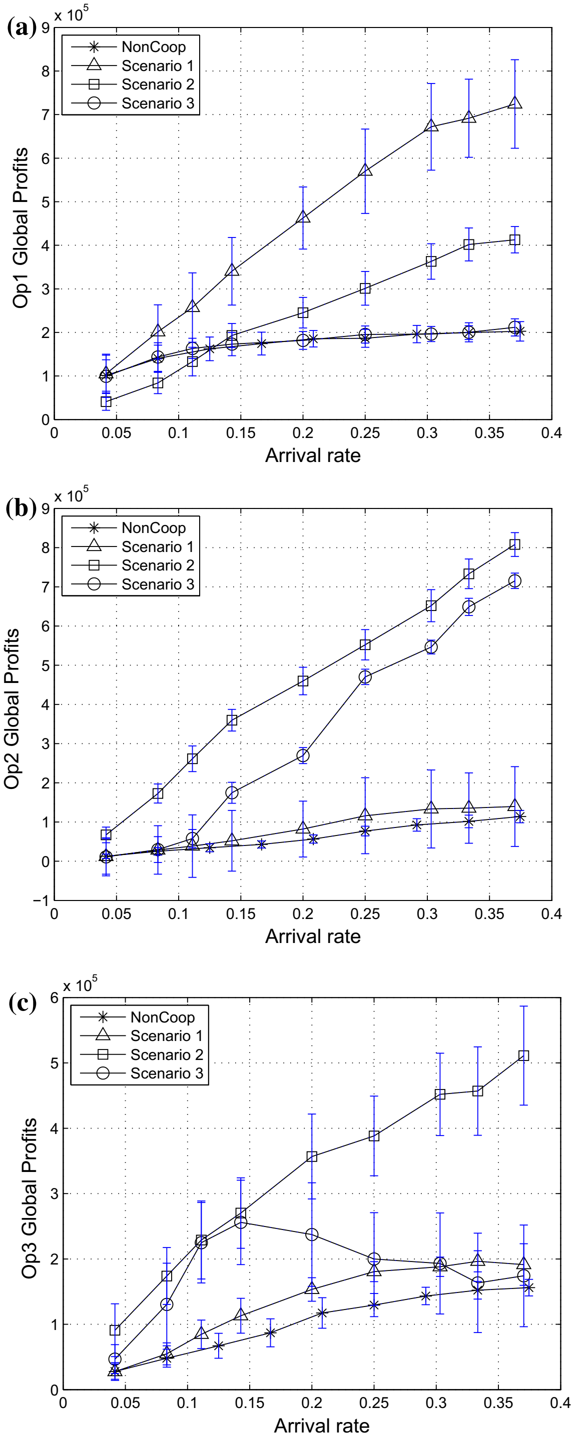


Fig. 7 Blocking rate variation with the pricing strategy. **a** Op_1 blocking rates comparison when applying the pricing strategy, Op_2 blocking rates comparison when applying the pricing strategy. Op_3 blocking rates comparison when applying the pricing strategy

Fig. 8 Profit variation with the pricing strategy. **a** Op_1 profits comparison when applying the pricing strategy. **b** Op_2 profits comparison when applying the pricing strategy. **c** Op_3 profits comparison when applying the pricing strategy



scenario 1 guarantees better profits. In fact, with scenario 1, Op_2 and Op_3 set a low service cost, and since Op_1 performs a high number of transactions to improve its client acceptance, this scenario guarantees the lowest cost, thus, better profits. However, scenario 2 comes in the second place. In fact, Op_1 transfers the majority of its client to Op_2 , which sets a high service cost in this scenario. Again, adopting a pricing strategy, with a high service cost, guarantees the best profits for Op_2 and the operator sharing high to medium capacity. Besides, it achieves good profit improvements for the operators with limited capacity.

4.2.2 Application of the Sharing Strategy

In this subsection, Op_2 will apply its sharing strategy and will reduce the amount of shared capacity from 100% to $\gamma_2 = 50, 30, 10\%$, keeping the same service cost 0.2 units/kB. Assume that Op_2 changes its sharing factor, while other operators share all their capacity with a sharing factor $\gamma_1 = \gamma_3 = 100\%$.

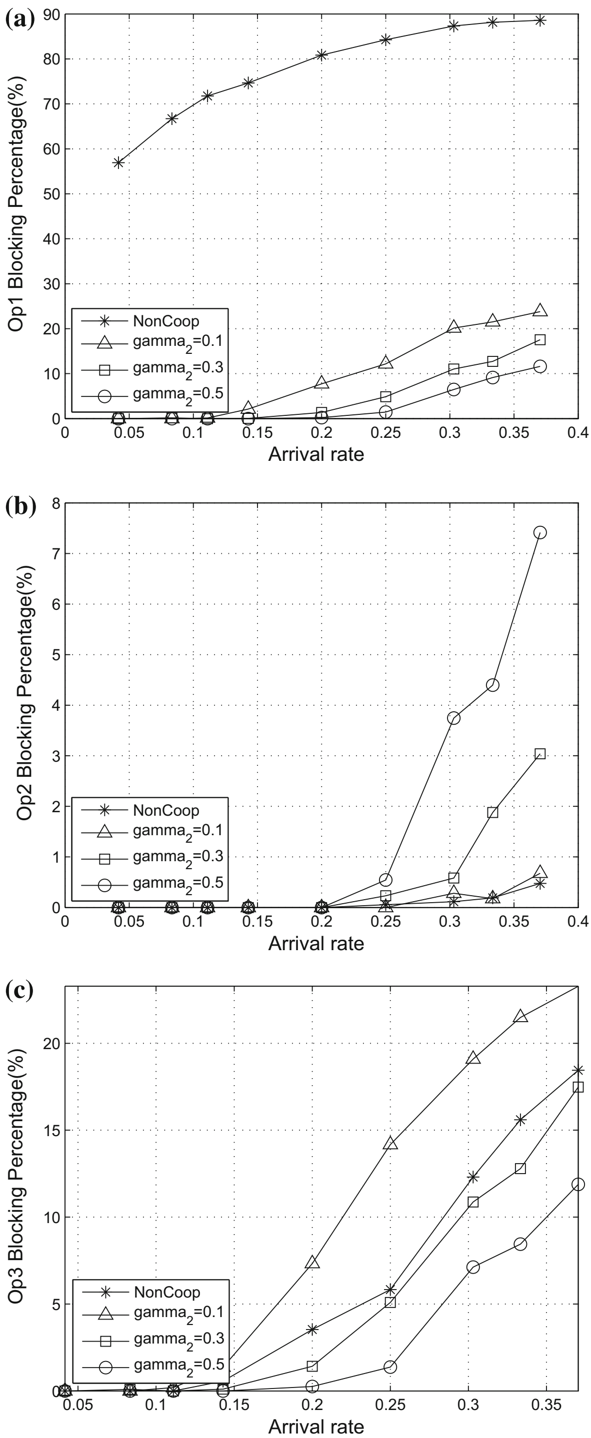
4.2.2.1 Blocking rate variation Figure 9a–c show the blocking rates of Op_1, Op_2 and Op_3 respectively, for the different sharing strategies of Op_2 and the non cooperation case. Previous results (see Fig. 5b) showed that, when Op_2 shares all its capacity in an open access mode (with $\gamma_2 = 100\%$), it was penalized by a high number of guest users, which increased its blocking rates. When this operator changes its sharing strategy and reduces the amount of shared capacity, its blocking rates are improved Fig. 9b. For low arrival rates below 0.2, the blocking rates of Op_2 with different γ 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. They are maintained below 1% with $\gamma_2 = 10\%$. Reducing the amount of shared capacity helped Op_2 to limit the guest flow and guarantee its clients satisfaction. However, the blocking rates of Op_1 and Op_3 increase when Op_2 reduces the shared capacity, since it reduces the acceptance of guest users coming from these operators.

Hence, changing the sharing strategy improves the client acceptance of Op_2, but affects the clients satisfaction of other operators in the sharing system. The blocking rates of other operators, having smaller capacity and performing a lot of transactions, increase when Op_2 reduces the amount of shared capacity.

4.2.2.2 Profit variation Figure 10a–c show the global achieved profits, for Op_1, Op_2 and Op_3 respectively, for the different sharing strategies and the non cooperation case. First, one can see that when Op_2 reduces the amount of shared resources, the achieved profits of all sharing operators decreases.

In fact, the revenue of Op_1 with the lowest capacity, depends strongly on the payment of the transferred users. Therefore, when Op_2 adopts a low sharing factor γ_2, the user blockings of Op_1 increase, thus, reducing its profits Fig. 10a. For Op_2, sharing the highest capacity, the profit improvement depends strongly on the service cost gained from serving guest users. Therefore, when it reduces the sharing factor γ_2, Op_2 serves less guest users and the achieved profits decrease Fig. 10b. Op_3, sharing a medium capacity, 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 service cost gained from Op_1 and the income from transferred users at high arrival rates. Therefore, at low and medium arrival rates, Op_3 achieves the same profits whatever is the sharing strategy of Op_2

Fig. 9 Blocking rate variation when Op_2 changes its sharing strategy. **a** Op_1 blocking rates comparison when applying the sharing strategy. **b** Op_2 blocking rates comparison when applying the sharing strategy. **c** Op_3 blocking rates comparison when applying the sharing strategy



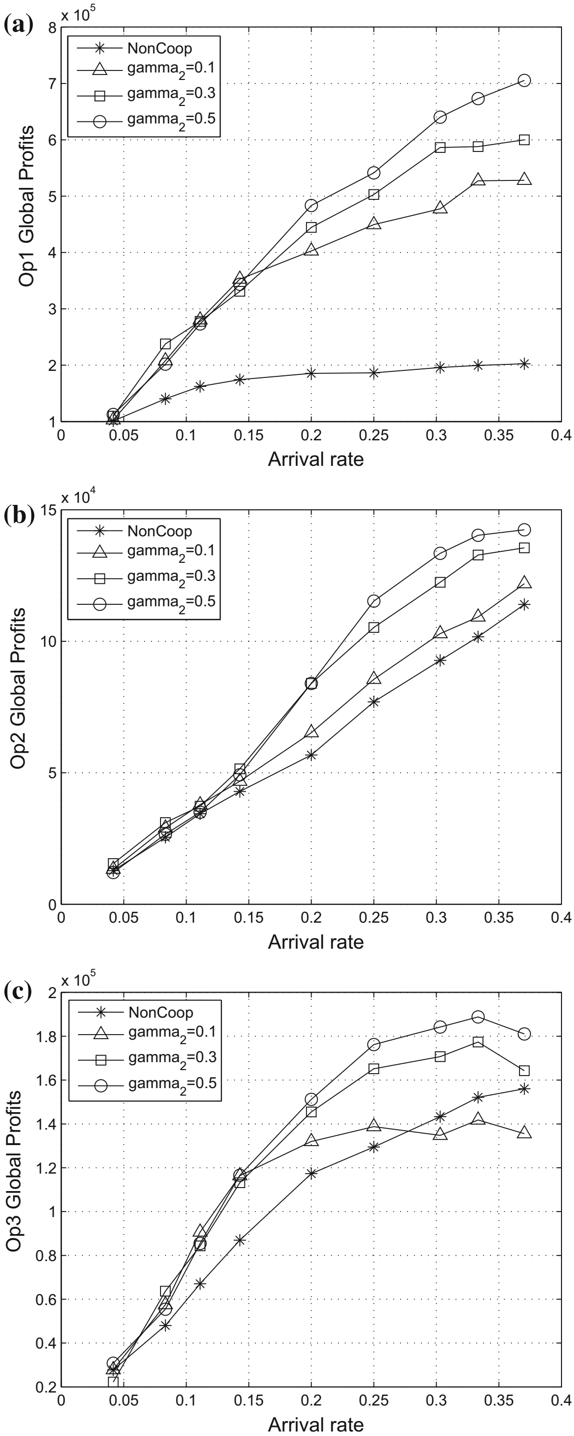


Fig. 10 Profit variation when Op_2 changes its sharing strategy. **a** Op_1 profit comparison when applying the sharing strategy. **b** Op_2 profit comparison when applying the sharing strategy. **c** Op_3 profit comparison when applying the sharing strategy

Fig. 10c. But, at high arrival rates, when Op_2 reduces its sharing factor γ_2, Op_3 is unable to transfer its clients for more incomes, which reduces its profits.

Hence, the sharing strategy of Op_2, does not affect the profit improvement at low and medium arrival rates. But, when the system is very loaded, at high arrival rates, the profits of all operators of the sharing system decrease with γ_2.

4.3 Strategy Comparison

In this subsection, the best pricing strategy of Op_2, that consist of setting the highest service cost in the system, is compared to the best sharing strategy (considering the blocking rate improvement), that consists of reducing the amount of shared capacity. Results will highlight the advantages for Op_2 when applying each of these strategies and how it effects the network performance and profits of other sharing operators. For this objective, three scenarios will be compared:

1. The first scenario referred to the open access mode, with strategy vectors $\left[c_1^t, \gamma_1\right] = [0.9,\ 1]$, $\left[c_2^t, \gamma_2\right] = [0.1,\ 1]$ and $\left[c_3^t, \gamma_3\right] = [0.2,\ 1]$ for Op_1, Op_2 and Op_3, respectively.
2. In the second scenario, Op_2 applies its pricing strategy, with a strategy vectors $\left[c_1^t, \gamma_1\right] = [0.9,\ 1]$, $\left[c_2^t, \gamma_2\right] = [0.9,\ 1]$ and $\left[c_3^t, \gamma_3\right] = [0.2,\ 1]$ for Op_1, Op_2 and Op_3, respectively.
3. In the second scenario, Op_2 applies its sharing strategy with $\gamma_2 = 10\%$, with strategy vectors $\left[c_1^t, \gamma_1\right] = [0.9,\ 1]$, $\left[c_2^t, \gamma_2\right] = [0.1,\ 0.1]$ and $\left[c_3^t, \gamma_3\right] = [0.2,\ 1]$ for Op_1, Op_2 and Op_3, respectively.

4.3.1 Blocking Rate Variation

Figure 11a–c shows the blocking rates for Op_1, Op_2 and Op_3, respectively, for different strategies of Op_2.

Notice that, when the system became very loaded, at high arrival rate in Fig. 11b, Op_2 could guarantee the lowest blocking rates and thus the best client acceptance by adopting a sharing startegy, *i.e,* by limiting the amount of shared capacity. Moreover, with the pricing strategy the blocking rates are higher, however, they still in an acceptable range for such system state and are better than the blocking rates in an open access mode. For Op_1 and Op_3, the lowest blocking rates are achieved when Op_2 adopts the pricing strategy Fig. 11a and c, respectively, and the open access mode comes in the second place.

4.3.2 Profit Variation

Figure 12a–c show the global profits for Op_1, Op_2 and Op_3, respectively, for different strategies of Op_2.

For Op_2, Fig. 12b, the pricing strategy guarantees the highest profits; with this strategy Op_2 achieve the highest income from guest users. It is the same for Op_3. In fact when Op_2 applied the pricing strategy a number of guest users from Op_1 are transferred to Op_3, which added new incomes to this operator. For Op_1, with the lowest capacity, a high number of transaction are needed to improve the client acceptance, hence, the open access mode guarantees its users service with the lowest service cost, thus with the best profits.

Fig. 11 Operators' blocking rate with strategy comparison. **a** Op_1's blocking rate comparison. **b** Op_2's blocking rate comparison. **c** Op_3's blocking rate comparison

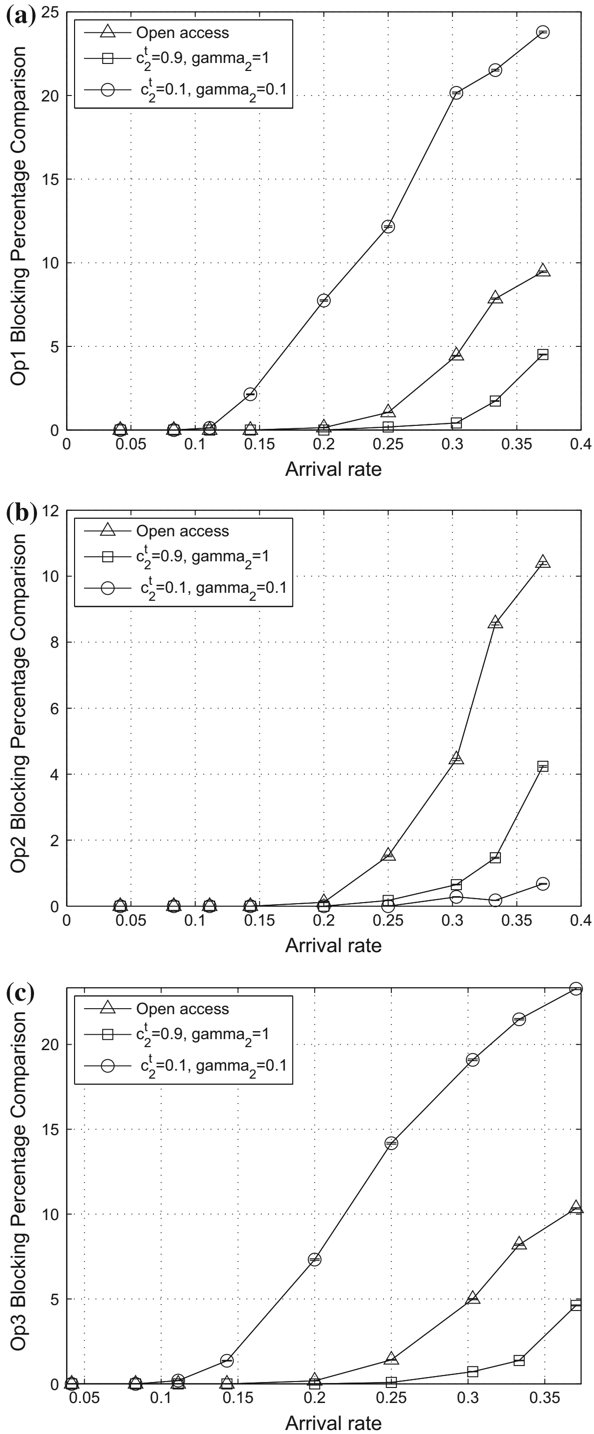
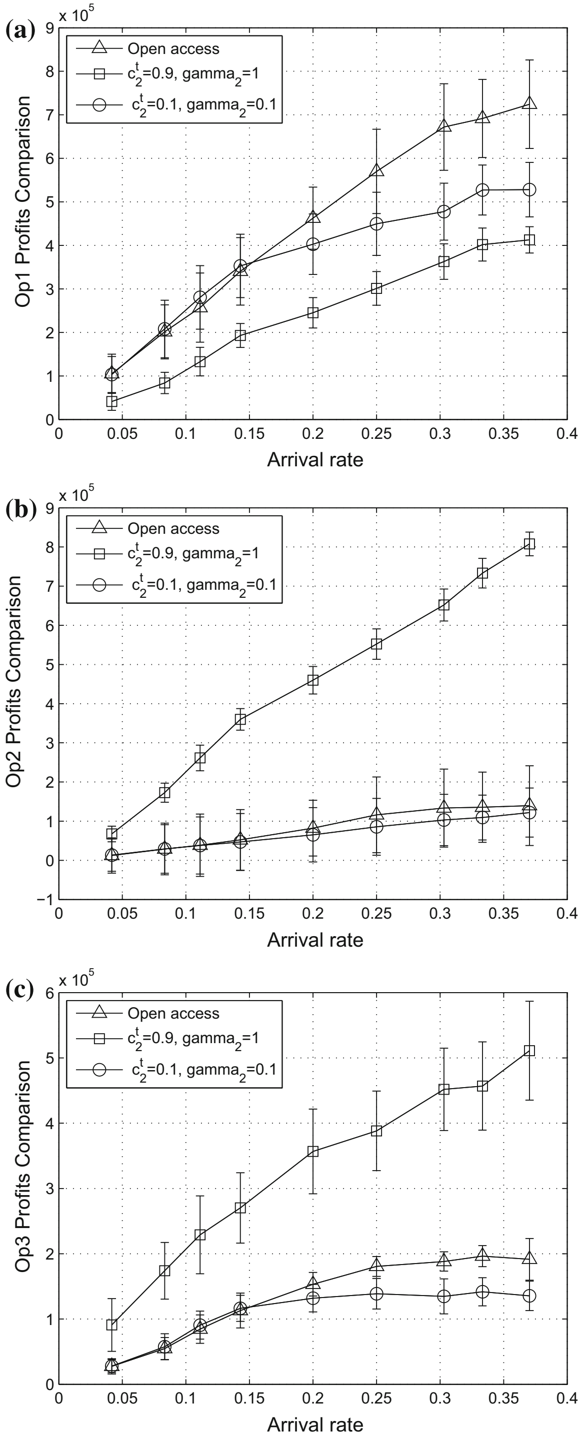


Fig. 12 Operators' profits comparison. **a** Op_1's global profits comparison. **b** Op_2's global profits comparison. **c** Op_2's global profits comparison



Hence, the operator with the highest capacity guarantees the lowest blocking rates when adopting a sharing strategy. However, it affects the client acceptance of other partners and reduces the achieved profits. With the pricing strategy, the blocking rates of such operator are higher, but in an acceptable range, and the blocking rates of other partners are the lowest. With this strategy, operators sharing high and moderate capacities guarantee the best profits.

5 Conclusion

This paper introduced a strategic access selection algorithm for the selection decision, S-AS, to optimize the cooperation benefits in multi-operator sharing environment. Both pricing and sharing studies are investigated.

Simulation results showed that when applying the pricing strategies, the best values of blocking rates for the operator sharing the highest capacity are achieved when it sets its service cost to the highest service price in the group, while other operators set the service cost equal to their service price. This strategy has improved the client acceptance of the operator sharing the highest capacity and all other sharing operators. Besides, it guarantees the best profits for the operators sharing high to medium capacity and achieves good profit enhancement for the operators with limited capacity. When applying the sharing strategies, results showed that reducing the amount of shared capacity helped the operator sharing the highest capacity to limit the guest flow which improved its client's acceptance. Moreover, reducing the shared capacity decreased the profits of all operators in the system espacially when its is very loaded. Furthermore, the comparison of the best pricing and sharing strategies in terms of the network performance and profits showed that the pricing strategy guarantees the best profits for the operators sharing high to moderate capacities and the best client's acceptance for the operators sharing low to moderate capacities.

Futur work will investigate the best decision for the sharing factor and service cost, considering the strategies of all operators. The interaction between the operators of the sharing system can be modeled using game theory.

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