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Admission Control Policies for Revenue and Utility Maximization in IEEE 802.16 networks

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Abstract

This paper introduces admission control policies for the IEEE 802.16 standard which aim to reach three main goals: restrict the number of simultaneous connections in the system so that the resources available to the scheduler are sufficient to guarantee the QoS requirements of each connection, support the service provider expectations by maximizing the revenue, and maximize the users satisfaction by granting them additional resources. The proposed policies are evaluated through simulation experiments.

1 Introduction

Admission control mechanisms regulate the traffic load in the network so that the scheduler can furnish the bandwidth required by each connection. In IEEE 802.16 networks [1], users request the establishment of a new connection by informing the desired type of service along with a set of QoS requirements. Such service differentiation may result in users over-requesting resources to maximize their individual satisfaction. An effective way to encourage users to choose the service that is most appropriate for their needs, is through network pricing. Therefore, integrating pricing and admission control is attractive to service providers not only from an economic perspective, but also to address resource management issues.

This paper proposes policies for the admission control mechanism in IEEE 802.16 networks which aim to maximize both the service provider and the users satisfaction. In particular, the proposed policies have the following goals: 1) to restrict the number of simultaneous connections in the system in order to avoid the saturation of the wireless channel, 2) to meet the service provider expectations by maximizing the network revenue, and 3) to maximize the users satisfaction, which is called utility in this paper, by providing resources beyond those required in the admission process.

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The first admission control policy presented in this paper is the simplest one, since it meets only the first goal. It was proposed by the authors in [7]. The decision strategy for the admission of new connections consists in guaranteeing that the sum of the minimum rate requirements of all the accepted connections is less than the available capacity. This strategy guarantees that the resources available to the scheduler are sufficient to provide the bandwidth requirement of each connection.

The second and the third policies meet all the three goals. The second policy uses mixed integer linear programming formulation and the third policy employs a heuristic algorithm.

Most admission control solutions available in the literature [5, 6, 12, 13] consider only minimum rate requirements in the decision process. Nevertheless, the amount of resources that should be reserved for a connection exceeds the minimum rate requirement and it depends on the type of service being solicited. The policy proposed in [7] as well as those in this paper differ from the existing ones by the accountability of the overhead generated by the type of service being solicited (such as the overhead incurred by the bandwidth request mechanism). This strategy leads to a more precise estimate of the amount of resources that should be allocated at each admission decision.

Moreover, the policies proposed in this paper provide methods for revenue and utility maximization, which are important factors for the successful deployment of the IEEE 802.16 networks on comercial scale. Rong *et all* [4] also proposed a policy for revenue, utility, and fairness maximization, however, they assume that all connections using the same type of service have the same minimum traffic rate requirement which does not comply with the IEEE 802.16 standard. The policies introduced in this paper do not make such assumption.

2 Standard-compliant admission control policy

To make the paper be self-contained, this section presents the admission control scheme proposed by the authors in [7]. This policy considers only the minimum rate requirement in the IEEE 802.16 standard. It accepts a new connection when the following condition is satisfied:

$$(C_{reserved} + TR_{ij} \leq C) \tag{1}$$

TR_{ij} is the traffic rate that should be guaranteed to the new connection j of service type i; $C_{reserved}$ is the capacity reserved to the existing connections which is equal to $\sum_{i=1}^{n} TR_{ij}$; and C is the capacity available for the uplink scheduler, i.e., the amount of uplink bandwidth that the scheduler can allocate for data and bandwidth requests transmission [9] [10].

A connection requesting admission informs, among other parameters, its *minimum reserved traffic rate* requirement ($minTR_{ij}$). However, this rate is not sufficient to serve the connection when taking into account the overhead generated by the type of service flow being solicited. Therefore, instead of considering only the *minimum reserved traffic rate* requirement, the TR_{ij} value also includes an estimate of the bandwidth overhead generated by service flow i.

According to the IEEE 802.16 standard, UGS and ertPS connections receive grants in intervals defined by the *unsolicited grant interval* (ugi) parameter. The grant size for

UGS connections is fixed, based on the *maximum sustained traffic rate* of the service flow (which is equal to the *minimum reserved traffic rate* for this service). Although the size of the grants allocated to the ertPS connections varies according to the amount of requested bandwidth, the minimum size that should be guaranteed is based on the *minimum reserved traffic rate*. In this way, for both types of service flows, the base station should guarantee grants with size equals to $grantSize_{ij}$, where:

$$grantSize_{ij} = minTR_{ij} * ugi_{ij} \tag{2}$$

Equation 2 gives the grant size in bytes. However, grants are given in slots, thus, the number of slots assigned to a connection j is approximated to the smaller integer larger than or equal to $grantSize_{ij}/slotSize$. This normalization may result in bandwidth waste when the $grantSize_{ij}$ is not a multiple of the number of bytes that can be transmitted in one time slot ($slotSize$). Consequently, the rate that will be used by an UGS (ertPS) connection can be larger than the *maximum sustained traffic rate* (*minimum reserved traffic rate*) requirement. To account for this overhead, the value of TR_{ij} for UGS and ertPS connections is computed as follows:

$$TR_{ij} = \frac{\lceil \frac{grantSize_{ij}}{slotSize} \rceil * slotSize}{ugi_{ij} + tj_{ij}} \tag{3}$$

In Equation 3, $\lceil \frac{grantSize_{ij}}{slotSize} \rceil$ gives the grant size in slots. Grants should be provided in intervals of duration ugi_{ij} with maximum jitter tj_{ij} (defined by the parameter *tolerated jitter*). Multiplying the grant size in slots by the size of one slot in bytes and dividing this value by the sum $ugs_{ij} + tj_{ij}$ gives the minimum rate that should be guaranteed for either UGS or ertPS connections.

Besides the *minimum reserved traffic rate*, rtPS and nrtPS connections also need periodic grants to request bandwidth (unicast polling)[1]. Therefore, the rate that should be guaranteed for these connections is equal to the sum of the $minTR_{ij}$ requirement and the rate used by the unicast polling as follows:

$$TR_{ij} = minTR_{ij} + \frac{upSlots * slotSize}{upi_{ij}} \tag{4}$$

where $upSlots$ is the number of slots used by the unicast polling and upi_{ij} is the value provided by the *unsolicited polling interval* parameter. nrtPS connections do not provide the upi_{ij} parameter, however, according to the standard, this interval can be chosen by the BS.

Best effort connections are always accepted since they do not have QoS requirements.

3 Optimal admission control policy for revenue and utility maximization

The admission control policy proposed in this section aims at maximizing the network revenue and utility. For service providers, revenue is a primary concern, while from the user's perspective, the best admission control policy is the one that can achieve maximum utility or, equivalently, maximum transmission rate.

The optimal revenue and utility strategy is introduced in the context of IEEE 802.16 networks as follows. Let r_i denotes the revenue rate of a service-i connection. The revenue obtained with the admission of a new connection j is equivalent to the minimum rate requested by j and is given by the function $r_i * minTR_{ij}$. In the same way, let u_i denotes the utility rate of a service-i connection. Then, the utility gain function is defined as $u_i * extraTR_{ij}$, where $extraTR_{ij}$ is the extra rate, beyond the minimum requested rate, to be allocated to connection j. The value of $extraTR_{ij}$ cannot surpass the difference $maxTR_{ij} - minTR_{ij}$, so that the maximum rate requirement ($maxTR_{ij}$) is not violated.

In order to maximize the revenue, the admission controller should collect requests during time intervals to decide which ones should be accepted. For utility maximization, at each admission interval, the admission controller should decide which connections, either new or existing ones, should be granted additional resources. This optimization problem can be formulated as:

$$max \sum_{i=1}^{4} \sum_{j=m_i+1}^{n_i} x_{ij} r_i minTR_{ij} + \sum_{i=1}^{4} \sum_{j=1}^{n_i} u_i extraTR_{ij}$$

Subject to:

$x_{ij} \in \{0, 1\} \quad \forall i \in \{1, 2, 3, 4\} \quad \forall j \in \{m_i + 1, ..., n_i\}$ (R1)

$0 \le extraTR_{ij} \le maxTR_{ij} - minTR_{ij} \quad \forall i \in \{1, 2, 3, 4\} \; e \; \forall j \in \{1, ..., m_i\}$ (R2)

$0 \le extraTR_{ij} \le (maxTR_{ij} - minTR_{ij})x_{ij} \quad \forall i \in \{1, 2, 3, 4\} \; e \; \forall j \in \{m_i + 1, ..., n_i\}$ (R3)

$\sum_{i=1}^{4} \sum_{j=1}^{n_i} (TR_{ij} + extraTR_{ij}) \le C$ (R4)

where

- n_i: total number of service-i connections (existing connections + new connections soliciting admission);
- m_i: number of existing service-i connections;
- $minTR_{ij}$: minimum traffic rate requirement for the connection j, where i is the type of service and j is the connection ID;
- $maxTR_{ij}$: maximum traffic rate requirement for the connection j;
- TR_{ij}: minimum rate that should be allocated to connection j which is given by Equation 3 for UGS and ertPS connections and by Equation 4 for rtPS and nrtPS connections;
- $extraTR_{ij}$: amount of rate, beyond the minimum rate requirement, which will be allocated to the connection j;
- r_i: revenue rate of a service-i connection;
- u_i: utility rate of a service-i connection;

- x_{ij}: variable used to indicate whether or not a new connection should be admitted;
- C: capacity available for the uplink scheduler;

In the proposed formulation, i varies from 1 to 4 to designate UGS, ertPS, rtPS, and nrtPS connections. Restriction R1 determines that the value of the variable x_{ij} should be either 0 or 1. A connection j is rejected when $x_{ij} = 0$ and accepted when $x_{ij} = 1$. Restriction R2 guarantees that the extra rate ($extraTR_{ij}$) allocated to an existing connection does not violate its maximum rate requirement. The amount of extra resources allocated to existing connections is updated at each admission interval in order to adapt it to the network dynamics. Restriction R3 guarantees that the extra rate allocated to a new connection is zero when the connection is rejected and that it does not violate the maximum rate requirement when the connection is admitted. It is important to note that this policy never allocates extra resources to UGS connections, since minimum and maximum rate requirements are the same for this type of service. Restriction R4 guarantees that the sum of the resources reserved for all connections does not surpass the capacity available for the uplink scheduler.

4 Heuristic admission control policy for revenue and utility maximization

The admission control policy introduced in this section uses a heuristic algorithm to maximize revenue and utility. As the policy proposed in the previous section, this algorithm decides which connections should be admitted as well as the amount of extra resources that should be reserved for both new and existing connections.

The algorithm is based on the cost x benefit tradeoff. The benefit gained by accepting a new connection j is equal to the sum of the revenue and the utility gain provided by it ($r_i * minTR_{ij} + u_i * extraTR_{ij}$). The cost of admitting a connection is equal to the amount of resources that should be reserved ($TR_{ij} + extraTR_{ij}$). Connections whose demands can be met are admitted according to the decreasing order of the associated rewards (given by the ratio between the benefit and the cost).

For existing connections, the algorithm decides the amount of extra resources that should be allocated to maximize the utility. The benefit gained by allocating extra resources for an existing connection j is equal to $u_i * extraTR_{ij}$, while the cost is $extraTR_{ij}$. If the reward obtained by allocating extra resources for an existing connection is higher than the reward reached by the admission of a new connection, the new connection is rejected and the existing connection receives extra resources.

The Algorithm $MaxRevenueUtilityCAC$ presents the steps taken at the beginning of each admission interval. First, the algorithm calculates the reward provided by new connections whose values for TR_{ij} are less than the available capacity and by existing connections not using the UGS service. New connections requesting more bandwidth than the available capacity are rejected, while existing UGS connections are not considered since their minimum and maximum rate requirements are the same. To calculate the benefit and the cost values, it is necessary to define the amount of extra resources to be allocated for each connection

($extraTR_{ij}$). The algorithm sets $extraTR_{ij}$ to the maximum value it can assume. For new connections, this value is equal to the minimum between the available capacity after the connection is accepted ($C_{available} - TR_{ij}$) and the difference between the minimum and the maximum rate requirements ($maxTR_{ij} - minTR_{ij}$). For existing connections, the maximum value for $extraTR_{ij}$ is equal to the minimum between the available capacity and the difference between the minimum and the maximum rate requirements.

In the second step, the algorithm selects the connections providing the highest reward values. Whenever a connection is selected, the available capacity is updated by subtracting $TR_{ij} + extraTR_{ij}$, if it is a new connection, or $extraTR_{ij}$, if it is an existing connection, from $C_{available}$. When the available capacity is less than the amount that should be reserved for a selected connection, the algorithm returns to the first step to recalculate the $extraTR_{ij}$ values as well as the reward values for the remaining connections. The algorithm finishes when there is no available capacity or when all the admission and allocation decisions have been taken.

5 Simulation Experiments

To conduct this study, an ns-2 module for IEEE 802.16 networks was developed [8] [11].

The simulated network consists of a BS, with the SSs uniformly distributed around it. Five different types of traffic were used: voice, voice with silence suppression, video, FTP and WEB, which are associated with UGS, ertPS, rtPS, nrtPS, and BE services, respectively.

The voice model used was an exponential "on/off" model with mean duration of the "on" and of the "off" periods equals to 1.2 s and 1.8 s, respectively. During the "on" periods, 66-byte packets are generated at every 20-ms [14]. The voice with silence suppression model used the Enhanced Variable Rate Codec (EVRC) [3], with packets generated every 20 ms employing Rate 1 (171 bits/packet), Rate 1/2 (80 bits/packet), Rate 1/4 (40 bits/packet) or Rate 1/8 (16 bits/packet). Video traffic was generated by real MPEG traces [16]. The WEB traffic was modeled by a hybrid Lognormal/Pareto distribution, with the body of the distribution corresponding to an area of 0.88 modeled by a Lognormal distribution with a mean of 7247 bytes and the tail modeled by a Pareto distribution with mean of 10558 bytes [15]. FTP traffic was generated using an exponential distribution with a mean of 512 KBytes.

The unsolicited grant interval for the UGS and for the ertPS service is 20 ms. The unsolicited polling interval for the rtPS service is 20 ms and for the nrtPS service is 1 s.

Each rtPS connection has its own minimum reserved traffic rate and maximum sustained traffic rate requirements, which vary according to the mean rate of the transmitted video. The nrtPS service has minimum reserved traffic rate requirement of 200 Kbps, and maximum sustained traffic rate requirement of 300 Kbps. The BE service does not have any QoS requirement.

The revenue rates are set as follows: 4 for the UGS service, 3 for the rtPS service, 2 for the ertPS service, and 1 for the nrtPS service. The same values are used for the utility rates except for the UGS service, which has utility rate equal to 0, since connections using

Algorithm GreedyMaxRevenueUtilityCAC

1. insert new and existing connections in the *reward_array*
2. **for** each connection j in *reward_array* **do**
3.   **if** j is a new connection **then**
4.   **if** $TR_{ij} > C_{available}$ **then**
5.   reject j and delete it from *reward_array*
6.   **else**
7. $extraTR_{ij} \leftarrow min(C_{available} - TR_{ij}, maxTR_{ij} - minTR_{ij})$
8. $benefit \leftarrow r_i * minTR_{ij} + u_i * extraTR_{ij}$
9. $cost \leftarrow TR_{ij} + extraTR_{ij}$
10. $reward_{ij} \leftarrow benefit \div cost$
11.   **else**
12.   **if** j is a UGS connection **then**
13. $extraTR_{ij} \leftarrow 0$
14.   delete j from *reward_array*
15.   **else**
16. $extraTR_{ij} \leftarrow min(C_{available}, maxTR_{ij} - minTR_{ij})$
17. $benefit \leftarrow u_i * extraTR_{ij}$
18. $cost \leftarrow extraTR_{ij}$
19. $reward_{ij} \leftarrow benefit \div custo$
20. **while** $C_{available} > 0$ **and** *reward_array* $!= \emptyset$ **do**
21.   search *reward_array* for the connection j with the highest value for $reward_{ij}$
22.   **if** j is a new connection **then**
23.   **if** $TR_{ij} + extraTR_{ij} <= C_{available}$ **then**
24.   accept j with extra rate equal to $extraTR_{ij}$
25. $C_{available} \leftarrow C_{available} - (TR_{ij} + extraTR_{ij})$
26.   delete j from *reward_array*
27.   **else** go to step 2
28.   **else**
29.   **if** $extraTR_{ij} <= C_{available}$ **then**
30.   reserve to j extra rate equal to $extraTR_{ij}$
31. $C_{available} \leftarrow C_{available} - extraTR_{ij}$
32.   delete j from *reward_array*
33.   **else** go to step 2

this type of service do not receive extra resources.

The lifetimes of connections are exponentially distributed with average equal to 600 s for the rtPS connections and equal to 300 s for UGS, ertPS, and nrtPS connections. The connection arrival rates are governed by an exponential distribution with the mean varying from 60 s to 2 s for each type of service. In this way, under the lowest load, on average, one connection of each type of service arrives per minute, while under the highest load, an average of 30 connections of each type of service arrive per minute.

Each result was produced by running the simulation ten times with different seeds. The mean values and the 95% confidence intervals are shown in the figures.

6 Numerical Results

In this section, the policies proposed in Sections 2, 3, and 4 are, respectively, referred to as Simple AC, Optimal AC, and Heuristic AC.

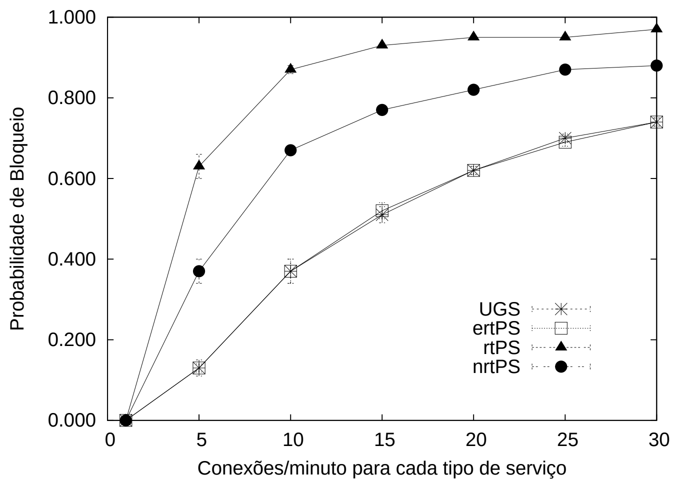

Figure 1: Blocking probability when using the Simple AC policy

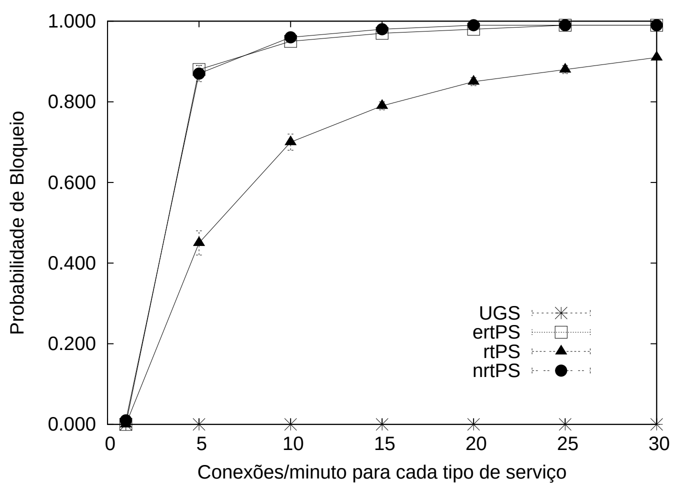

Figure 2: Blocking probability when using the Optimal AC policy

Figures 1, 2 e 3 present the blocking probability for the UGS, the rtPS, the ertPS, and the nrtPS services when using the proposed policies. When the Simple AC policy is used (Figure 1), the UGS and the ertPS services have similar blocking probability values. Moreover,

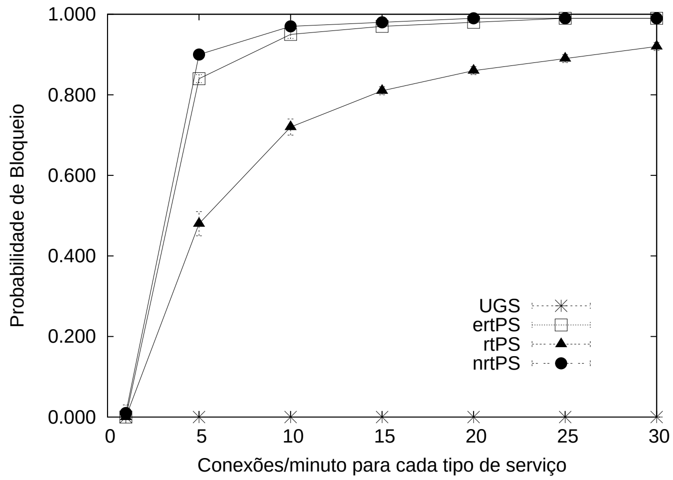

Figure 3: Blocking probability when using the Heuristic AC policy

UGS and ertPS connections are more likely to be accepted, while rtPS connections face the highest blocking probabilities. These results are due to the fact that this policy considers only the minimum rate requirements in the admission decision process and while UGS and ertPS connections require minimum rates of 26.4 Kbps and 6.4 Kbps, respectively, the minimum rate requirement of rtPS connections can be as high as 900 Kbps.

Figures 2 and 3 show that blocking probability values are very similar when using the Optimal AC and the Heuristic AC policies. In both cases, all the UGS connections are accepted regardless the load conditions. The UGS service provides a combination of low minimum rate requirement and high revenue rate value. Hence, by admitting a high number of UGS connections, the network can rapidly increase its revenue gain without having to reserve a great portion of its available resources, which explains the result obtained. On the other hand, ertPS and nrtPS connections are subject to high blocking probabilities. Both services produce low revenue and utility gain, while the nrtPS service also requires high minimum rates. By blocking a high number of ertPS and nrtPS connections, the admission control is able to admit a higher number of rtPS connections. Although rtPS connections require the reservation of high amounts of resources, they greatly contribute to the revenue generation since the rtPS service is associated with the second highest revenue rate and has the highest minimum rate requirements.

These results show how policies with different goals can affect users of different types of service. When the network is overloaded, a service provider may wish to promote a balanced blocking in order to avoid disparities as the ones observed in Figures 2 and 3, even if, as a consequence, it results in lower revenue gains. This can be accomplished by extending the proposed policies in order to minimize the difference between blocking probability values of different types of service.

Figure 4 presents the accumulated revenue gain achieved by the three proposed policies. As expected, the Simple AC policy generates the lowest revenue values since it does not maximize the revenue.

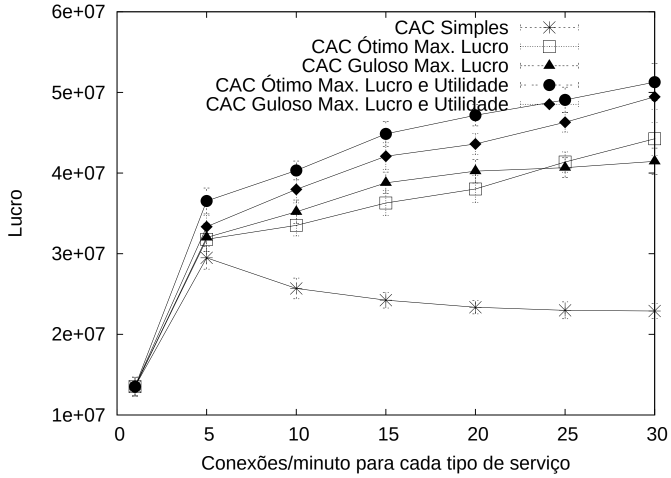

Figure 4: Revenue of Simple AC, Optimal AC and Heuristic AC policies

The revenue produced by the Heuristic AC policy is close to the one produced by the optimal approach regardless of connections arrival rate, but on the average, the Optimal AC policy produces higher revenues than the heuristic algorithm. On the other hand, Figure 5 shows that the Heuristic AC policy gives higher utility gain than the Optimal AC policy. These results are explained by the fact that, although both policies produce similar blocking, on average, the Optimal AC policy admits 1% to 2% more rtPS connections than does the Heuristic AC policy. By admitting less rtPS connections, the AC Heuristic policy produces lower revenues than the optimal approach, but it is able to allocate more additional resources for the admitted connections leading to higher utility gains.

Although not shown here due to space limits, the three admission control policies were tested in conjunction with the uplink scheduler proposed in [7] to evaluate their ability to support the scheduling mechanism in the provisioning of QoS. Simulation results show that the proposed policies are able to avoid saturation of the wireless channel so that the resources available to the scheduler are sufficient to guarantee the QoS requirements of each admitted connection.

Latency results were derived for the UGS and the ertPS connections in order to check whether they receive periodic grants as specified by the standard. Results were also derived to verify whether or not the average latency of the rtPS connections violates the maximum latency requirement. Moreover, throughput results were generated to check whether rtPS and nrtPS connections have their minimum traffic rate requirement guaranteed.

Latency and throughput results were very similar for all three admission control policies, which means that, in terms of QoS provisioning, the service provider could use the Simple AC policy which is the simplest one to be implemented. In case the service provider also wishes to maximize revenue and utility, the Heuristic AC is an attractive option, since it is simpler to implement than the Optimal AC policy and gives a near-optimal solution.

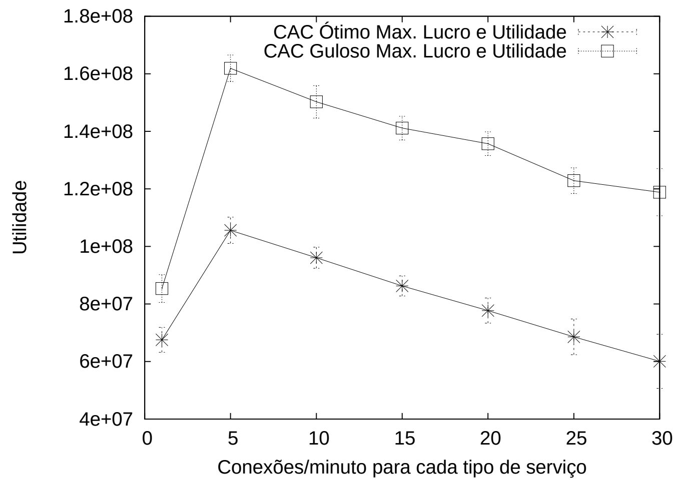

Figure 5: Utility of Optimal AC and Heuristic AC policies

7 Conclusions

This paper has introduced admission control policies for the IEEE 802.16 standard. The proposed policies restrict the number of simultaneous connections in the system so that the resources available to the scheduler are sufficient to guarantee the QoS requirements of each connection. Moreover, they furnish means to support the service provider and the users expectations, by maximizing the network revenue as well as the network utility.

Future work will include the investigation of mechanisms to promote balanced blocking for different types of service allowing the service provider to accommodate diverse levels of fairness.

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