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Improving Fairness in Multi Service Multi Layer Networks

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ABSTRACT

Fairness is an important but seldom addressed aspect in multi layer networks with traffic grooming capabilities. Often an excessive high blocking probability is observed for high capacity connections compared to small capacity connections. Similar, connections with more hops are more often blocked than those to the neighbor node.

In this paper, we present two extensions of a bandwidth fairness algorithm that is based on a call admission control (CAC). First, this algorithm will be generalized for any class-based system. Second, an improvement is presented in order to reduce the performance drawbacks.

Keywords: WDM, grooming, bandwidth fairness, distance fairness, CAC, performance evaluation

1. INTRODUCTION

Circuit switched multi layer networks like SDH/WDM or MPLS/WDM networks are one feasible network architecture that provide dynamics on all layers in order to cover the dynamics of IP traffic as well as to provide bandwidth adaptable connections. In literature, several routing and grooming schemes for such multi layer networks have been proposed for provisioning connections at different granularities, e. g. [1], [2]. These schemes are usually designed for minimizing the overall blocking probability or maximizing resource efficiency, but they do not consider fairness. The term fairness reflects that with respect to a certain service attribute, e.g. the required bandwidth, all independent connection requests having the same requirement will experience the same service quality, e. g., the same blocking probability, while different requirements lead to a well defined differentiation in the service quality. Since from both a users perspective as well as an operators perspective fairness is an important aspect, an additional mechanism has to be provided in order to ensure fair handling of connections. As this is usually at the cost of penalizing the overall network performance, these mechanisms have to be carefully designed and optimized.

In this paper, the two aspects *bandwidth fairness* and *distance fairness* are addressed. We describe an extension of a fairness algorithm in order to apply it to both kinds of fairness, the bandwidth and the distance fairness. With respect to bandwidth, we define a network to be fair if the blocking probability of a number of connections with a certain total capacity C is independent from the granularities requested. This means the blocking probability of N_1 connections of a bandwidth of B_1 is equal to N_2 connections of bandwidth B_2 as long as $N_1 \cdot B_1 = N_2 \cdot B_2$.

With respect to distance fairness, two definitions are considered. First, assuming a nation-wide network, the fairness target can be the independence of the blocking probability from the distance (T1). Second, in international networks it may be required that similar to the bandwidth fairness definition N_1 connections with a distance of D_1 hops have the same blocking probability as N_2 connection with a distance of D_2 hops if $N_1 \cdot D_1 = N_2 \cdot D_2$ (T2).

The remainder of this paper is structured as follow: The basic fairness algorithm as well as the extensions are described in Section 2. In Section 3, the behavior of the schemes is investigated by simulative performance evaluation. Finally, conclusions and an outlook are provided in Section 4.

2. ALGORITHM

In [3], a CAC algorithm is presented that provides fairness among connections of different bandwidth granularities according to the definition above. The CAC decides if a path with sufficient free capacity is available, whether the connection request is rejected for fairness reasons or can be accepted. For this, the described CAC algorithm monitors the blocking probability of each bandwidth class independent of the others. It accepts all connection requests of bandwidth j as long as the blocking probability of connection requests of this bandwidth j, i.e. p_j, is greater than a target blocking probability which is here the mean blocking probability of all connection requests of any bandwidth P. If and only if p_j is smaller than P, it randomly rejects the connection request with the rejection probability $Q = (P - p_j)/P$ (referred in [3] as rejection threshold).

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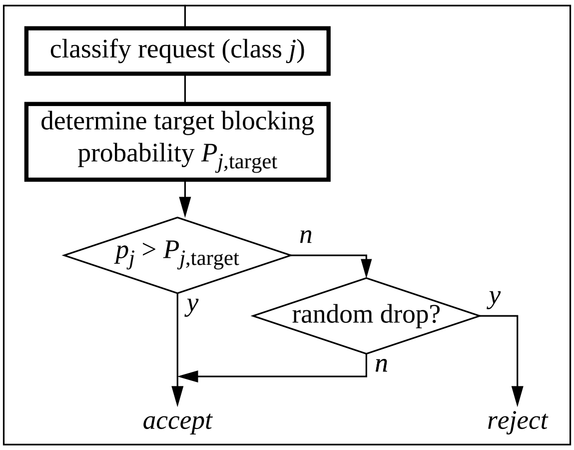

Fig. 1 Principle CAC algorithm

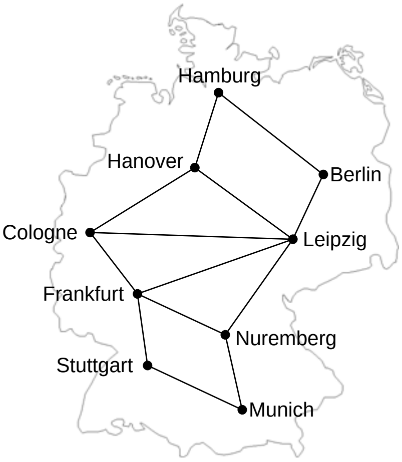

Fig. 2 Germany Network Scenario

In order to equalize the blocking probabilities with respect to their bandwidth as described above, a normalization of the blocking probabilities to the systems smallest granularity is used. Assuming the small capacity connections to be independent of each other, the so called *blocking probability per unit line speed* p'_j is introduced that is calculated by $p'_j = 1 - \sqrt[j]{1 - p_j}$ for connections of bandwidth *j*.

Based on this given algorithm we present two extensions in the following. First, we extend the algorithm to be applicable for any class-based systems, e. g. distances. Second, we modify the formula for the rejection probability Q as the original scheme is too aggressive in case of very low blocking probabilities.

2.1 Generalization of the algorithm

Basically, the CAC algorithm provides a fairness mechanism for a system with different independent connection classes. Its main function is to randomly block connections in order to achieve a certain target blocking probability for each class. For applying this algorithm to other class-based systems, we identified two functions that have to be adapted accordingly (**Fig. 1**): first, a scheme for classifying connection requests to a certain class and, second, a scheme for determining the target blocking probabilities per class. In the bandwidth fairness case described above the connections are classified based on the required bandwidth and the target blocking probability is defined by the mean blocking probability normalized to the unit line speed.

In case of distance fairness, we classify the connections according to the distance between the connections endpoints, i. e., the length of the shortest path between source and destination node in the optical layer. The target blocking probability can be calculated in two ways (cf. Section 1). If the service quality shall be independent of the distance (T1), no normalization is introduced and the mean blocking probability as well as the blocking probabilities per class are used as they are monitored. Otherwise, analog to the bandwidth fairness, a normalization per unit hop length is introduced if the blocking probability shall be dependent on the distance (T2).

2.2 Modification of the rejection probability

Analyzing the formula for the rejection probability Q shown above it can be seen that for small p_j and P the algorithm is too aggressive and blocks too many connections, especially if the monitoring interval is short. Thus, we developed a new formula that is less aggressive at the cost of small fairness penalties.

The blocked connections can be separated into two groups: First, connections that are rejected by the network as no free path is available, and second, connections that are blocked by the CAC. We use the probabilities $P_{j,\,\text{NW}}$ and $P_{j,\,\text{CAC}}$ for a connection request of bandwidth *j* being blocked by the network or rejected by the CAC, respectively.

The target of the CAC system is to control the normalized blocking probability of a connection class, i. e., the sum of the network blocking probability and blocking probability due to rejection by the CAC, such that a given target blocking probability is reached: $P_{j,\,\text{target}} = P_{j,\,\text{NW}} + P_{j,\,\text{CAC}}$. With the probability $1 - P_{j,\,\text{NW}}$, a connection request is not blocked by the network and has to be handled by the CAC. There, it is either accepted if $p_j > P_{j,\,\text{target}}$ holds or with the probability Q randomly blocked. So, the blocking probability due to (random) rejects by the CAC can be calculated by $P_{j,\,\text{CAC}} = Q \cdot (1 - P_{j,\,\text{NW}})$. Using this, the required rejection probability can be calculated as follows:

$$Q = \frac{P_{j,\,\text{target}} - P_{j,\,\text{NW}}}{1 - P_{j,\,\text{NW}}}$$

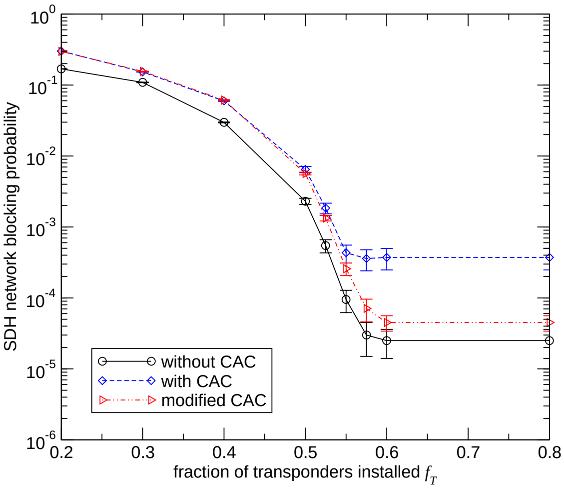

Fig. 3 Blocking probability for bandwidth fairness

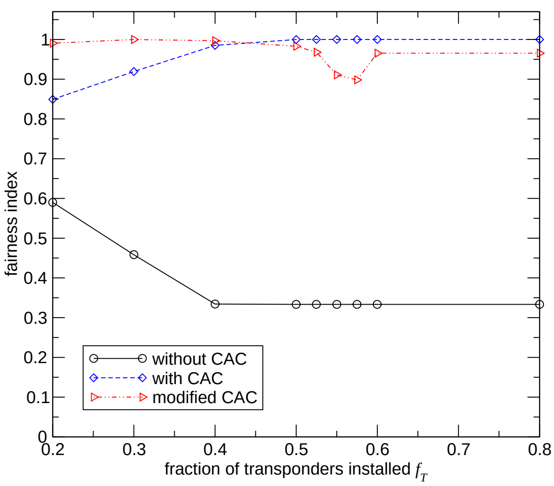

Fig. 4 Fairness with bandwidth based CAC

3. CASE STUDY

In the following, we present the results of a case study that has been performed by event-driven simulation using a model of an enhanced automatically switched SDH/WDM multi layer network. SDH/WDM multi layer networks consist of multi layer nodes with cross connects on the SDH layer as well as on the WDM layer connected by a number of transponders [5].

We use a hypothetical reference network topology shown in **Fig. 2** and a static traffic demand matrix obtained from a population model. The link capacities are dimensioned according this traffic matrix based on shortest path routing such that blocking probabilities on all links are equal in the Erlang model [4]. The offered traffic load is fixed at 70% of the static traffic.

For SDH/WDM multi layer nodes, the number of transponders is a crucial parameter, both, from a performance as well as from a cost perspective (cf. [1]). Thus, the *fraction of transponders installed* referred as f_T is introduced as the absolute number of transponders in the network normalized by the maximum number of transponders that can be used. The latter is limited by the number of outgoing wavelengths in a node.

Connection requests arrive according to a Poisson process with exponential holding times. A traffic mix consisting of 80% STM-1, 15% Gigabit-Ethernet (transported in VC-4-7v) and 5% STM-16 is used. The bandwidth of a wavelength is chosen to be STM-16. For routing and grooming, the integrated scheme WIR [1] is applied.

Finally, for measuring fairness, the *fairness index* introduced in [6] is used. It maps the performance metrics of any number of classes, e. g., the loss probabilities of different granularities or distances, to a dimensionless continuous absolute value between 0 and 1. If all values are equal and thus the system is fair, the fairness index is 1.

3.1 Bandwidth fairness

In **Fig. 3** the SDH network blocking probability with and without CAC is plotted versus the fraction of transponders installed f_T. We show the results for both rejection thresholds. In general, for a low f_T the networks performance is mainly limited by the transponder capacity whereas for a high f_T, the network capacity limits the performance. Comparing the results with and without CAC it can be seen that the CAC always increases the blocking probability. If the impact of the transponders dominates, almost the same results can be achieved independent of the formula for the rejection threshold. In case of the network limitation, the new formula outperforms by up to an order of magnitude.

In **Fig. 4**, for the same scenarios the fairness index is plotted versus the fraction of transponders installed f_T. Without CAC, the fairness is below 60% which is inacceptable. Detailed investigations show that for a high f_T almost only STM-16 connections are rejected. With CAC, the fairness is always better than 85%. Using the old formula, for a low f_T the fairness is slightly below 100% while for a high f_T, absolute fairness is reached. Using the new formula, almost 100% can be reached for low f_T while for a high f_T the fairness is around 95% which is still acceptable.

Concluding, the new formula reduces the total blocking probability for a high f_T at the cost of a slightly reduced fairness. Further, it increases the fairness for a low f_T without any impact on the blocking probability.

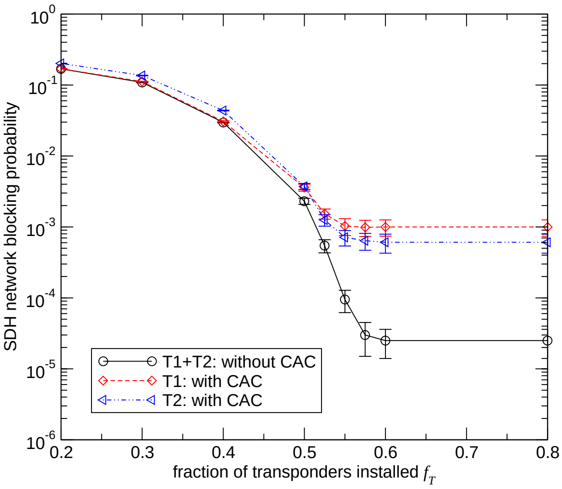

Fig. 5 Blocking probability for distance fairness

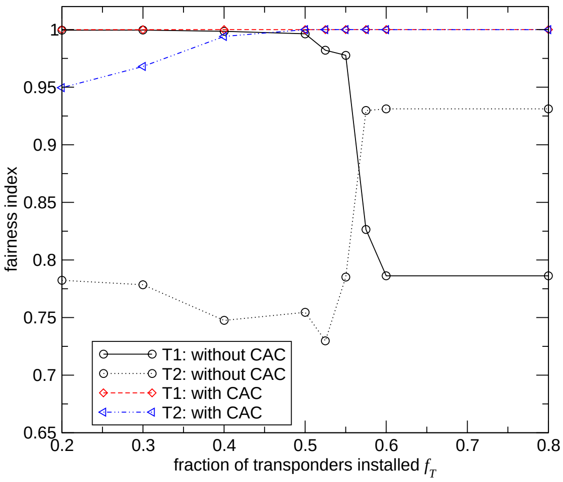

Fig. 6 Fairness with distance based CAC

3.2 Distance fairness

In **Fig. 5**, the SDH network blocking probability with and without CAC is plotted versus the fraction of transponders installed f_T. We show the results for both fairness targets, i. e. T1 and T2. It can be seen that similar to the bandwidth case above for a low f_T the blocking probability is only slightly increased whereas for a high f_T the CAC decreases the performance by an order of one magnitude.

In **Fig. 6**, for the same scenarios the fairness indices are plotted versus the fraction of transponders installed f_T. While without CAC the blocking probability does not depend on the fairness target, the different targets lead to different fairness indices also without CAC. With respect to target T1, for a low f_T the fairness target is achieved even without CAC whereas for a high f_T, the CAC is necessary for fairness. For target T2, without CAC the system is almost fair (93%) for a high f_T whereas for a low f_T the system is unfair. With CAC, both fairness targets can almost be reached. Only when equalizing the blocking probability with respect to the number of hops (T2), the system is still slightly unfair.

4. CONCLUSIONS

In this paper, we presented two extensions of a CAC based algorithm for bandwidth fairness. After introducing the fairness mechanism, we presented a generalization of this for any class based system. Further, we proposed an improved formula for the rejection probability in order to reduce performance penalties.

By performance evaluation we showed the applicability of the generalized fairness mechanism to the distance fairness issue based on two different definitions of bandwidth fairness. Further, in the bandwidth fairness scenario we pointed out the savings of the modified rejection probability with respect to the total blocking probability while keeping the fairness high.

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