An Approach to Off-line Inter-domain QoS-Aware Resource Optimization

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Abstract. Inter-domain traffic engineering is a key issue when QoS-aware resource optimization is concerned. Mapping inter-domain traffic flows into existing service level agreements is, in general, a complex problem, for which some algorithms have recently been proposed in the literature. In this paper a modified version of a multi-objective genetic algorithm is proposed, in order to optimize the utilization of domain resources from several perspectives: bandwidth, monetary cost, and routing trustworthiness. Results show trade-off solutions and "optimal" solutions for each perspective. The proposal is a useful tool in inter-domain management because it can assist and simplify the decision process.

1 Introduction

The main purpose of inter-domain resource optimization is to map incoming inter-domain traffic flows into inter-domain network resources, satisfying quality of service (QoS) requirements, while aiming at optimizing the use of network resources across autonomous systems (AS) boundaries. Network resources usage is, in any case, conditioned by existing Service Level Specifications (SLSs) that, in turn, result from the Service Level Agreements (SLAs) established between each domain and its neighbors. For the purpose of this paper, the terms 'domain' and 'autonomous system' are synonyms.

In order to describe the inter-domain relationships of an autonomous system, one can use a simple model, as shown in Fig. 1. An autonomous system is interconnected with other autonomous systems by means of its ingress and egress interfaces. For the propose of this paper, the terms 'interfaces' and 'links' are synonymous.

The service offerings between autonomous systems as well as their mutual responsibilities are described by means of Service Level Agreements. In general, each SLA defines a set of contractual, administrative and technical requirements. The latter are called Service Level Specifications. An SLS comprises several items or clauses, including identification, application scope, flow identification, traffic conformance, excess treatment, and performance guarantees.

In the context of the present work an SLS is characterized by an egress interface, an inter-domain QoS class *q* as proposed in [7], a destination prefix *d*, the corresponding maximum bandwidth requirements *b*, the monetary cost per unit of bandwidth *c* , and the route trustworthiness *r* associated to the SLS. The monetary cost component reflects the monetary cost associated with the established SLA. On the other hand the routing trustworthiness reflects the intra-domain routing costs associated with the egress interface, and the inter-domain routing costs like route quality, reliability and domain policies. An SLS entry for a domain has the following format:

`SLS entry = [egress interface, q, d, b, c, r]`

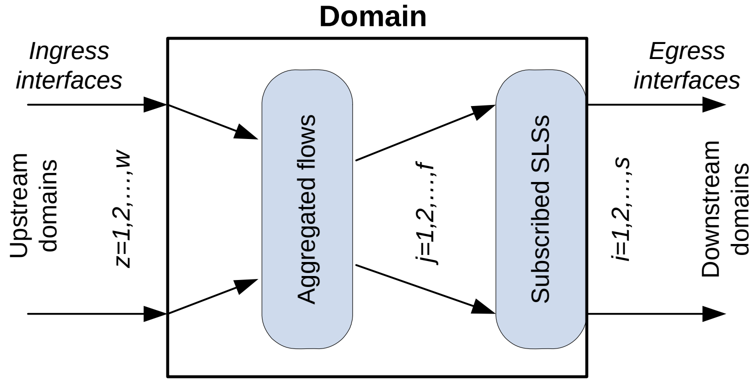

Fig. 1. Inter-domain relationship model

On the other hand, a domain receives from upstream domains a collection of *w* data flows towards other domains. Depending on the domain policy and on their common characteristics, such as destination and QoS class, these flows may be aggregated into *f* inter-domain traffic flows. The flows' common characterization includes the inter-domain class mapping *q* and the destination prefix *d*. That is, an aggregated flow entry has the following format:

`Aggregate flow entry = [ingress interface, q, d, a]`

where *a* is the bandwidth requirement of the aggregated flow. The flow will be mapped into one of the existing SLSs. The appropriate selection of the SLSs for the inter-domain traffic flows benefits the domain by improving the network resources, maximizes the profits [21] from a business point-of-view and, at same time, selects the most reliable routes according to internal and external information and business objectives. The first benefit is reached through a correct bandwidth load-balancing, the second through a minimization of the costs, and the third through a high value of routing trustworthiness. In contrast, in current networks this task is executed in a trial-and-error fashion.

The problem can be expressed by three objective functions (1), (2), and (3) that represent respectively the total costs for bandwidth, monetary cost and routing. Formally, the problem can be stated as follows. Let $I = \{1,2,...,s\}$ be the set of SLSs and $J = \{1,2,..., f\}$ the set of aggregated traffic flows. For each SLS *i* there is a given resource capacity, expressed in terms of bandwidth, $b_i > 0$. For each $i \in I$ and each $j \in J$ there is a given set of costs, $B_{i,j} > 0$, for bandwidth, $C_{i,j} > 0$, for monetary, and $R_i > 0$, for routing, for assigning an aggregated traffic flow *j* to an SLS *i*. Additionally, $z_{i,j}$ is an indicator function that returns 1 if the traffic flow *j* is assigned to SLS *i* and 0 otherwise. The mathematical formulation is as follows:

$$y_1 = \sum_{i=1}^{s}\sum_{j=1}^{f} B_{i,j} \cdot z_{i,j} \tag{1}$$

$$y_2 = \sum_{i=1}^{s}\sum_{j=1}^{f} C_{i,j} \cdot z_{i,j} \tag{2}$$

$$y_3 = \sum_{i=1}^{s}\sum_{j=1}^{f} R_i \cdot z_{i,j} \tag{3}$$

$$\text{subject to } \sum_{j=1}^{f} a_{i,j} \cdot z_{i,j} \le b_i, \forall i \in I, \tag{4}$$

$$\text{with } \sum_{i=1}^{s} z_{i,j} = 1, \forall j \in J, \tag{5}$$

$$z_{i,j} \in \{0,1\}, \ \forall i \in I, \forall j \in J. \tag{6}$$

The goal is to minimize the costs of (1), (2), and (3), where $B_{i,j}$, $C_{i,j}$, and R_i are respectively the cost functions for bandwidth, monetary, and routing as described in Sec. 3.1. The capacity constraint (4) ensures that the total resource requirements of the traffic flows assigned to each SLS do not exceed the available capacity. The assignment constraint (5) guarantees that each traffic flow is assigned to exactly one SLS.

Since we need to find the best solution considering all objectives at the same time, our problem falls into a multiple objective optimization problem. For this kind of problems genetic algorithms are a well known technique capable of finding the entire non-dominated Pareto front in a single run [1]. A Pareto front is a set of solutions, and a solution is said to be non-dominated if its components cannot be improved in terms of one objective without causing a simultaneous degradation in at least one of the other components [9]. The minimization problem is expressed formally as follows, for *n* objective functions with *m* optimization parameters:

$$\text{Minimize } y = f(x) = (f_1(x),...,f_n(x)) = (y_1,...,y_n) \in Y \qquad \textbf{(7)}$$

$$\text{and } x = (x_1,...,x_m) \in X \qquad \textbf{(8)}$$

With X as the parameter space and Y the objective space, x is called the decision vector and y the objective vector. A decision vector $a \in X$ is said to dominate a decision vector $b \in X$ if and only if:

$$\forall i \in \{1,...,n\} : f_i(a) \geq f_i(b) \wedge \exists j \in \{1,...,n\} : f_j(a) > f_j(b) \qquad \textbf{(9)}$$

The objective of the work presented in this paper is to propose the optimization of domain resources from multiple perspectives, namely from the bandwidth usage perspective, monetary cost perspective, in line with [21], and routing costs. For this, three objective functions are proposed, and our aim is supported by a multiple-objectives evolutionary algorithm especially designed to deal with these off-line interdomain traffic engineering issues.

In Section 2 of this paper an overview of related work is given. This is followed by a presentation of the proposed objective functions and the supported evolutionary algorithm in Section 3. In order to validate our work, an evaluation framework comprising two test scenarios, each one representing a type of Internet transit autonomous system [4], is presented in Section 4. Section 5 presents and discusses the obtained results. The conclusions and guidelines for further work are presented in Section 6.

2 Related Work

Several studies on intra-domain resource optimization, such as [12-15], can be found in the literature. In the case of inter-domain, references [8][16-19] constitute the framework for most of the current proposals.

Genetic algorithms have already been extensively used to solve network optimization problems [8][12-15][20][22]. These algorithms, belonging to the class of evolution strategies used in optimization, resemble the process of biological evolution, where each individual is described by its genetic code, called a chromosome. On the other hand each chromosome is composed of individual genes. In the problem in hand, a gene is the assignment of a single aggregate traffic flow to an SLS, and an individual (i.e., a chromosome) is a potential solution.

There are several examples of single objective proposals, like in [2] where different heuristic algorithms are compared, or in [6] where a weighted genetic algorithm is presented. Other proposals as in [22] address the minimization of inter-domain transit costs.

The proposal in [8] presents a multi-objective solution based on [9] that contemplates the cost minimization and the bandwidth cost minimization, for traffic engineering of best effort traffic. Our approach extends the use of routing trustworthiness costs for off-line traffic engineering.

To the best of the authors' knowledge, it is the first time an inter-domain optimization proposal includes simultaneous optimization of bandwidth costs, monetary costs, and routing costs. It is also the first time a parameter related to egress links and routing is used, combining internal, external, and business perspectives, which leads to a simplification of the egress link selection task. Lastly, a modified multi-objective genetic algorithm that simplifies the management task is proposed, allowing the choice of the perspective which best fits the objectives.

3 Proposal

This section describes the proposed cost functions and the evolutionary algorithm.

3.1 Cost functions

The off-line traffic engineering as considered in this paper consists of selecting the optimal mapping between sets of aggregated traffic flows and the associated sets of SLSs in such a way that the following the objectives are satisfied:

- minimization of the egress link bottleneck, thus improving the egress load-sharing
- minimization of the costs of egress links' usage, so as to maximize the domain business profit
- minimization of the routing costs, improving the link trustworthiness

The bandwidth objective function (10) was used in order to measure the egress interfaces bottleneck, allowing the correct load-balancing in these interfaces, where b_i is the available bandwidth on egress interface i (the agreed SLS) for some QoS class and destination and b_j the bandwidth of the aggregate flow j. The value 0.1 was added to the dominator in order to limit the values of $B_{i,j}$ to 100.

$$B_{i,j} = \frac{1}{(b_i - b_j + 0.1)^2} \tag{10}$$

$$C_{i,j} = c_i \cdot b_j \tag{11}$$

$$R_i = 100 - r_i \tag{12}$$

On the other hand, the monetary cost objective function (11) measures the charge to pay for using the established SLS i, by the aggregated flow j. It represents the domain expenses.

Lastly, the route trustworthiness objective function (12) measures aspects related to the egress links. This includes route fail history, link fail history, routing metrics history, intra-domain routing costs, and domain policies. The specific way to combine these data in order to obtain a value for the route trustworthiness is outside the scope of this paper. In this paper, this parameter takes values varying from 0 (link not used) to 100 (the best choice). The routing perspective is not a BGP weight, nor a routing metric, nor does it intend to replace the *local-pref* discretionary attribute [10].

3.2 The Algorithm

The proposed algorithm follows the proposal in [9]. The basic algorithm steps are presented in Fig. 2. It starts with the creation of the initial generation, where the individuals are created randomly. Then, an evaluating step based on the proposed objective functions (1),(2), and (3), with costs (10), (11), (12) respectively, follows. After that, and for a number of generations, a new generation of children is created that are compared with the corresponding generation of parents. From this comparison the better elements will compose the next generation of parents. The ranking step is done as proposed in [9].

```
Create the initial parent generation;
Evaluate the generation;
For a number of generations;
  Create the child generation;
  Evaluate both generations together;
  Rank both generations together;
  Replace worst parents with better children;
End
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Fig. 2. Algorithm basic steps

The algorithm has a time complexity of $O(MN^2)$ where M is the number of objectives and N the size of the population.

4 Evaluation Framework

In order to evaluate our proposal, two typical scenarios were built, a tier-1 and a non-tier-1 transit autonomous' systems, as proposed in [4]. The scenarios' characterization is presented in Table 1. The traffic matrices and the SLSs matrices were built using these values as basis, Weibull distributions for sources and destination prefixes [5], Weibull distributions for ingress and egress links [3], and 3 exponentially distributed QoS classes [11].

For each scenario the algorithm returned a Pareto front with a non-dominated population of individuals ranked according. The comparison was made between front individual's rank 1 solution and the "best" ones in relation to every single perspective: bandwidth, monetary cost and routing cost.

Table 1. Test scenarios characterization

AS level	Tier 1	Non-Tier 1 transit
Links	400	20
QoS classes	3	3
Bandwidth (sources)	0..100	0..100
Destination prefixes	14738	14738
Monetary cost	1..10	1..10
Route trustworthiness	0..100	0..100
Aggregated flows	84400	50400

5 Results

The two scenarios presented in Table 1 were used for testing the assignment algorithm as described in Sec. 4. Fig. 3 shows the comparison between the 4 different solutions returned by the algorithm for the Tier 1 scenario, for each of costs. The figure shows the per cent increase in cost in relation to the minimum cost solution for the correspondent perspective (with 0%).

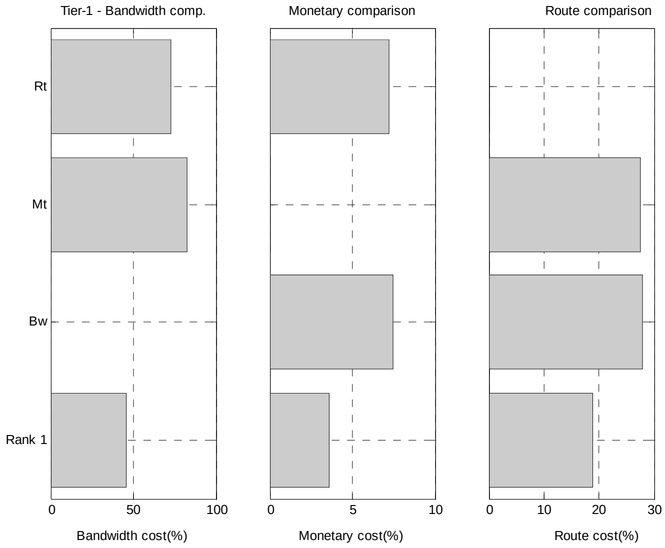

Fig. 3. Tier 1 results – comparison in percentage with lowest cost solution for bandwidth costs (*left*), monetary costs (*middle*), and routing costs (*right*)

When only the “best” bandwidth perspective is selected (*row two from the bottom in all graphics*) we have got the lowest costs for bandwidth but higher costs for monetary and route perspectives. On the other hand, if the selected individuals are the “best” from the monetary point-of-view (*row three from the bottom in all graphics*) we have got the lowest monetary cost, but high costs for bandwidth and route perspectives. The same we can say for the “route” perspective (*top row in all graphics*).

The bottom row in all graphics shows the individuals in the first rank, as returned by the algorithm. In this case the solution is not as good as when a perspective is selected individually, but has better costs compared with the worst cost values returned by the other solutions.

In the Fig. 4 a comparison between the four different solutions for the non-Tier 1 transit scenario, for each of the costs perspectives, is presented. The figure shows the per cent increase in cost in relation to the minimum cost solution for the correspondent perspective (with 0%). Comparatively, the results are similar to Tier 1.

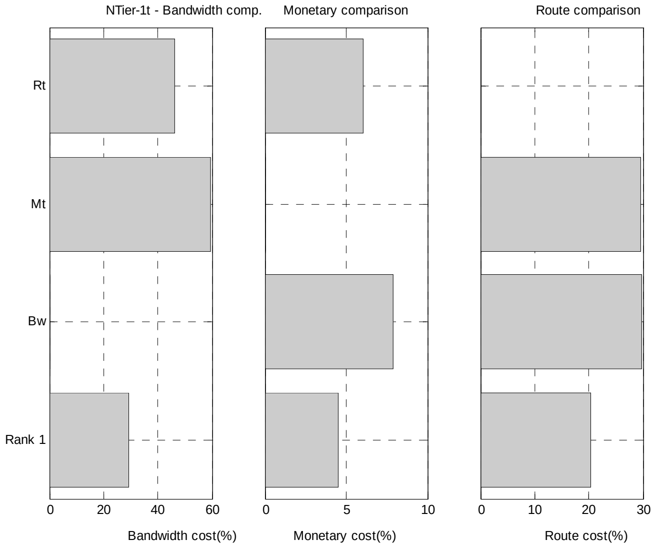

Fig. 4. Non-Tier 1 transit results –comparison in percentage with lowest cost solution, for bandwidth costs (*left*), monetary costs (*middle*), and routing costs (*right*)

6 Conclusions

Inter-domain QoS-aware resource optimization is one of the main challenges of current traffic engineering. Based on a modified version of a multi-objective genetic algorithm [9] and using typical models of transit autonomous systems, our proposal presents a set of solutions. They include trade-off solutions and “best” solutions from single perspectives optimizations. These solutions can be used to generate domain policies that, in turn, may influence routing decisions.

This paper also introduces a new kind of traffic engineering factor that simplifies the selection of the egress links: the route trustworthiness.

As a general conclusion, one can say that the presented proposal can be a useful tool in domain management because it simplifies the decision process by presenting the optimal costs either in terms of individual perspective, or in terms of trade-off between all perspectives.

Further work will address the algorithm's refinement and efficiency (the latter with the objective of reducing the computational complexity) and methods to compute route trustworthiness.

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