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Multi-Objective Third-party Approach for Service Class Mapping among Multiple Providers in the Internet

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***Abstract*—The third party (3P) model has been recognized as a perspective approach for different interprovider quality of service (QoS) solutions. In this paper, we address 3P-based mapping of services classes among heterogeneous providers' networks, which constitute an end-to-end (E2E) path. We propose and investigate a novel, highly flexible mapping scheme, which enables fulfillment of E2E network performance objectives, whereas minimizing interconnection costs. Starting from E2E service requirements, the proposed scheme uses goal programming technique to select the most appropriate service class in each domain on the path. Results of the comparative analysis of the proposed scheme and the two existing 3P-based schemes have clearly demonstrated superiority of our proposal in terms of accuracy, flexibility, and capability to support deployment of various business objectives.**

***Index Terms*—Goal programming, interprovider negotiation, third party, quality of service.**

I. INTRODUCTION

Recent trends in Internet development including cloud computing, mobility, content distribution, Internet of things, and the big data paradigm pose new architectural challenges for network interconnection in the future Internet [1]. Enhanced solutions for quality of service (QoS) provisioning are still needed, particularly regarding end-to-end (E2E) service negotiation, performance monitoring and measurements for inter-domain performance assessment. The basic bilateral approach [2], which assumes service negotiation only between the adjacent providers, fails to meet E2E requirements. On the other side, heterogeneity of the existing providers' networks, including different intra-domain QoS architectures, complicates the problem of establishing QoS-enabled E2E paths.

The third-party (3P) approach has been recognized as a promising solution for the interprovider QoS delivery [3]. It assumes that a trusted, authorized intermediary (3P agent) performs service negotiation, performance measurements, and business transactions among a group of providers. In this paper we address 3P-based mapping of service classes among multiple domains that constitute an E2E path. Mapping is needed to overcome the problem concerning different specification of service classes in different QoS architectures, which might be implemented in domains on E2E path. The objective of our work is to propose and investigate a highly flexible mapping algorithm, which should enable achievement of E2E performance objectives, whereas minimizing interconnection costs.

The rest of the paper is organized as follows. Section II explains motivation and related work. A novel algorithm for mapping of service classes among providers' networks has been proposed in Section III. Section IV contains performance evaluation of the proposed algorithm. Section V concludes the paper.

II. MOTIVATION AND RELATED WORK

So far, the 3P-based solutions have been addressed in the literature regarding different aspects of the interprovider QoS provisioning. A proposal for interprovider service level agreements (SLAs) validation has been presented in [4], assuming deployment of monitoring and measurement system through assignment of partial responsibility to the 3P agent. A proposal of a multi-dimension and autonomous QoS evaluation and monitoring system, relying on trusted 3P-servers is presented in [5]. A hierarchical approach has been considered in [6], by introducing the concept of multi-level service exchanges, which mediate in service negotiation in the group of subordinated domains. Opportunities for development of new business models through network independent, autonomous, trusted third party agents have been highlighted in [7].

On the other side, algorithms for service class mapping among providers have not been widely addressed. It has been stated that "mapping often results in applications being carried in either over- or under-engineered service classes,

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potentially wasting resources or lowering performance assurance” [3]. However, the absence of uniformly and universally defined service classes is a reality; hence, mapping is inevitable and the challenge is to make it more precise, less complex, and more efficient.

Static class mapping between well-known core and access QoS architectures has been proposed under the EuQoS project [8]. The concept of meta-QoS-class, proposed in [2], provides the limits of the QoS parameter values that two locally defined classes in adjacent providers’ networks must respect in order to be bound together. The generic service specification framework, proposed in [9], enables description of QoS classes in each domain using generic parameter format and their optional values. An intelligent mapping algorithm is then applied at domain boundaries during service negotiation process to select the most suitable service class in each domain.

Research work presented in [10], [11] and [12] reveals the advantages of the 3P-based class mapping with respect to fairness, flexibility of class selection and compliance with different QoS models. Conformance Matching Scheme (CMS) is a 3P-based algorithm for mapping of service classes on E2E path, starting from E2E QoS requirements [10]. The CMS runs in two stages: in the first stage, the algorithm prepares per-domain QoS requests, whereas in the second stage, it selects the most suitable class in each domain by calculating the closest conformance between the required and the offered service level. The algorithm has further been enhanced by introducing the option to select a policy for allocating per-domain QoS boundary values (Policy-based CMS, P-CMS) [11]. However, both the CMS and the P-CMS perform class mapping relying on purely technical parameters, i.e., performance metrics like delay, jitter, and packet loss rate.

A multi-constraint approach to service class mapping has been proposed and evaluated in [12]. The constraints involve fulfillment of QoS requirement and minimization of the overall interconnection costs. The foundation for this mapping is laid on a suitable 3P-based Integer Programming (3PIP) scheme. This scheme has an inherent limitation, because it fails to provide a solution in the case of constraint breaking.

The motivation for this work is to propose a multi-objective multi-constraint 3P-based approach to class mapping, which provides high-level control of mapping parameters, tightly bounded with E2E service requirements, and takes into account interconnection costs. This can be achieved using goal programming (GP) [13], a multi-criteria decision making technique, which is able to provide solutions fulfilling conflicting objectives and multiple constraints. Specification of objectives and constraints set enables mapping process to be done more accurately.

III. GOAL PROGRAMMING-BASED MAPPING SCHEME

The process of E2E SLA negotiation via 3P agent is depicted in Fig. 1. We suppose that QoS manager (QM) represents a per-domain entity, which is responsible for intra-domain QoS management and for communication with the 3P agent through an appropriate signalling protocol.

The 3P agent collects information about providers’ offers, which are formulated through differentiation of service classes. Each service class is specified in terms of: (1) relevant performance metrics like delay, jitter and packet loss rate (PLR), and (2) interconnection costs, which refer to operational costs of generating, transiting and terminating the traffic (e.g., in terms of cost per bandwidth unit).

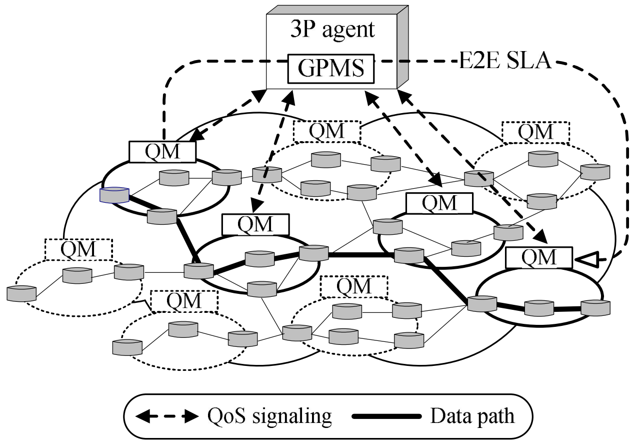

Fig. 1. End-to-end SLA negotiation via 3P agent.

We further propose the Goal Programming-based Mapping Scheme (GPMS), which is performed in the 3P agent. The GPMS selects the most appropriate service class in each domain on the path on the basis of E2E service performance request, providers’ performance offers (in terms of delay, jitter and PLR), and the offered interconnection costs. We adopt the Degree of Correspondence (*DC*) concept, originally proposed in [10], to assess capability of fulfilling QoS requirements. In general, for the observed service class, *DC* can be defined at domain or E2E level, for each performance metric or for the overall QoS. Definition of *DC* depends on the metric nature, e.g., additive, concave, multiplicative or indirectly multiplicative. Details about the rules for composition of performance metrics on E2E path can be found in [14].

Let $«_{j,\mathrm{req}}$ and $«_{j,\mathrm{off}}$ be the required and the offered E2E values of performance metric *j*, respectively. In this work, index $j = 1,2,3$ denotes delay, jitter and PLR, respectively. In order to evaluate the GPMS, we observe the DC_j^{E2E}, which denotes the *DC* parameter at E2E level, for performance metric *j*. It is calculated as follows

$$DC_j^{\mathrm{E2E}} = \frac{«_{j,\mathrm{req}}}{«_{j,\mathrm{off}}}, \tag{1}$$

where $j = 1, 2$.

$$DC_j^{\mathrm{E2E}} = \frac{\left|\log «_{j,\mathrm{off}}\right|}{\left|\log «_{j,\mathrm{req}}\right|}, \tag{2}$$

where $j = 3$. Equations (1) and (2) generally stand for additive and indirectly multiplicative performance metrics, respectively [10]. The value $DC_j^{\mathrm{E2E}} = 1$ denotes perfect match of the offered and the required E2E QoS, for metric *j*. If $DC_j^{\mathrm{E2E}} < 1$, the offered E2E service is worse than the required one. Similarly, $DC_j^{\mathrm{E2E}} > 1$ means that the offered E2E service is better than the required one.

The GPMS uses multi-GP approach [13], which assumes that multiple objectives are defined, while at the same time satisfying posed constraints. The proposed method searches for all available class mappings on all available E2E paths. The objective function *Z* should incorporate fulfillment of QoS requirements and minimization of E2E interconnection costs. Regarding QoS requirements, the ideal solution is to achieve perfect match between the required and the offered QoS, i.e., $DC_j^{\mathrm{E2E}} = 1$. If this is not feasible, the algorithm selects classes in a way that assures the value of DC_j^{E2E} to be as close as possible to 1.

Assume that 3P agent manages the group of *N* domains. Domain *d* ($d = 1,\ldots,N$) specifies K^d service classes. The offer of domain *d*, regarding service class *k* ($k = 1,\ldots,K^d$), is then expressed by a set of parameters $\{ «_{j,k}^d \mid j = 1,2,3 \}$, and c_k^d. Parameter $«_{j,k}^d$ refers to the offered value of performance metric *j*, for service class *k* in domain *d*. Parameter c_k^d denotes the interconnection cost of domain *d* for service class *k*.

We define auxiliary variables y^d and x_k^d, denoting domain's presence on E2E path and class selection, respectively

$$y^d = \begin{cases} 1, & \text{if domain } d \text{ is on the path,} \\ 0, & \text{otherwise,} \end{cases} \tag{3}$$

where $d = 1,\ldots,N$.

$$x_k^d = \begin{cases} 1, & \text{if class } k \text{ in domain } d \text{ is selected,} \\ 0, & \text{otherwise,} \end{cases}. \tag{4}$$

where $k = 1,\ldots,K^d$.

Regarding E2E QoS fulfillment, GPMS searches for classes according to the following rules

$$\sum_{d=1}^{N} \sum_{k=1}^{K^d} y^d \times x_k^d \times «_{j,k}^d + ¢_j^- - ¢_j^+ = «_{j,\mathrm{req}}, \tag{5}$$

where $j = 1,2$.

$$\sum_{d=1}^{N} \sum_{k=1}^{K^d} y^d \times x_k^d \times (-\log(1 - «_{j,k}^d)) + ¢_j^- - ¢_j^+ = = -\log(1 - «_{j,\mathrm{req}}), \tag{6}$$

where $j = 3$. Equations (5) and (6) stand for additive and indirectly multiplicative metrics, respectively. In (5) and (6), $¢_j^-$ and $¢_j^+$ ($¢_j^-, ¢_j^+ \geq 0$) are auxiliary variables called positive and negative deviation, respectively. Positive and negative deviations quantify the distance from the required value, i.e., $¢_j^-$ signifies offer of better value and $¢_j^+$ signifies offer of worse than required value for performance metric *j*.

The GPMS accounts for constraints related to QoS requirements according to (5) and (6), by incorporating them into objective function, depending on weights assigned to individual goals. We minimize deviation probabilities for all required metrics along with interconnection cost over *N* domains. In analytical terms, the objective function *Z* is

$$Z = \min \left\{ \sum_{j=1}^{3} \sim_j \times (¢_j^- + ¢_j^+) + \sim_c \times \sum_{d=1}^{N} \sum_{k=1}^{K^d} y^d \times c_k^d \right\}, \tag{7}$$

where $\sim_j$ and $\sim_c$ are weights assigned to performance metrics and interconnection cost, respectively. The GPMS provides additional flexibility in class mapping through prioritization. For example, each provider which initiates E2E service request is allowed to specify the importance of performance and cost aspects by assigning respective weight values.

Aside from weights $\sim_j$ and $\sim_c$, it is possible to specify limitations to deviation variables $¢_j^-$ and $¢_j^+$, resulting in mappings that provide specific ranges of better or worse performance than required. By establishing such a flexible environment, 3P agent may perform mapping that better suits to providers' business objectives bearing in mind cost-performance trade-off.

IV. PERFORMANCE EVALUATION

We evaluate the GPMS in two steps: (1) by comparing the proposed scheme with the two previous 3P-based schemes, P-CMS [11] and 3PIP [12], and (2) by varying the weight $\sim_c$ assigned to cost parameter. The compared algorithms have been implemented in MATLAB.

TABLE I. SPECIFICATION OF DOMAINS SERVICE CLASSES.

Domain	Class	Delay (ms)	Jitter (ms)	PLR	Cost (MU)
A1 (access)	1	40	10	10^{-5}	40
	2	80	30	10^{-4}	20
	3	120	–	10^{-4}	15
A2 (access)	1	20	15	10^{-6}	55
	2	50	20	10^{-5}	30
	3	70	30	$5\mathrm{x}10^{-5}$	20
	4	120	–	10^{-4}	17
R1 (regional)	1	15	10	10^{-6}	75
	2	50	30	10^{-5}	60
R2 (regional)	1	12	6	10^{-5}	80
	2	–	–	10^{-4}	70
C (continental)	1	45	5	10^{-5}	90
	2	100	15	$5\mathrm{x}10^{-4}$	65
	3	120	40	10^{-4}	55

We observe an E2E path, which is typical for the international traffic and is constituted of five hierarchically ordered domains [15] – two of them are access (stub), whereas the other three are transit (two regional domains and one continental domain). In order to make relevant comparison with previous 3P-based schemes, we adopt specifications of domains' service classes from [12] (Table I). Hence, the observed E2E path is A1–R1–C–R2–A2. It should be noted that interconnection costs, expressed in fictive monetary units (MU), actually represent cost per transfer of bandwidth unit across the observed domain.

E2E service requests are specified in Table II, bearing in mind typical QoS requirements and recommended objectives from [16].

TABLE II. SPECIFICATION OF E2E SERVICE REQUESTS.

Metric	**Service request**					
	1	**2**	**3**	**4**	**5**	**6**
Delay (ms)	150	200	400	400	600	–
Jitter (ms)	60	60	80	–	–	–
PLR	10^{-4}	10^{-3}	10^{-3}	10^{-4}	10^{-4}	10^{-4}

Table III contains a qualitative comparison of the three mapping schemes. The P-CMS is not cost-aware, whereas the 3PIP and GPMS are cost-aware schemes. Impairment budget refers to an E2E performance impairment contributed by one or more providers on the path. According to [17], there are static, pseudo-static, signaled and impairment accumulation approaches to impairment budget allocation. P-CMS uses signaled approach to determine per-domain impairment allocation, whereas 3PIP and GPMS allocate impairment on E2E level independently of the number of providers on the path using impairment accumulation approach. Hence, P-CMS calculates per-domain requests according to selected policy for allocation of performance impairment budgets. Thus, it achieves fairness on the count of additional computational and implementation complexity. Cost-aware 3PIP and GPMS schemes rely solely on providers' offers. The GPMS offers high flexibility through prioritization of objectives and adjustment of deviation variables. In contrast, 3PIP allows only the specification of E2E QoS, whereas P-CMS may optionally assign weights on particular domain characteristics.

TABLE III. QUALITATIVE COMPARISON OF MAPPING SCHEMES.

Mapping scheme	**Cost-aware**	**Impairment budget allocation**	**Per-domain QoS requests**	**Flexibility**
P-CMS	No	Signaled	Yes	Medium
3PIP	Yes	Accumulation	No	Low
GPMS	Yes	Accumulation	No	High

Comparative analysis has further been conducted by calculating E2E *DC* parameters for individual performance metrics (DC_j^{E2E}, $j = 1,2,3$) and E2E interconnection costs ($\sum_{d=1}^{5} c_k^d$). In the GPMS, equal weights have been assigned to performance metrics and interconnection cost, i.e., $\sim_j = \sim_c = 1$. The obtained results are depicted in Fig. 2, for six service requests (from Table II).

It is noticeable that the GPMS provides the most accurate mapping with regards to E2E performance requests, because the values of DC_j^{E2E} are closest to 1, in most cases. This means that over-engineering and under-engineering are minimized. In the cases when P-CMS and 3PIP achieve better performance matching, the GPMS introduces a trade-off between cost and performance. In other words, for such requests, GPMS decides that it is better to offer slightly worse performance for lower price. This trade-off may be additionally controlled through modification of parameters $\sim_j$ and $\sim_c$.

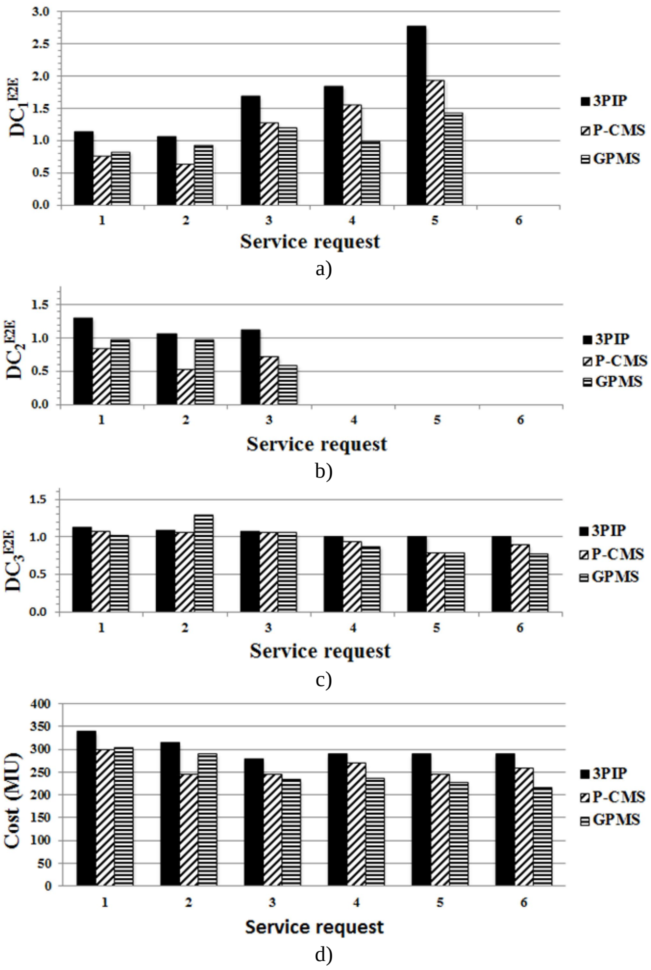

Fig. 2. E2E performance and costs for different service requests and mapping algorithms: a) DC_1^{E2E}; b) DC_2^{E2E}; c) DC_3^{E2E}; d) E2E interconnection costs.

In order to analyse flexibility of GPMS, we further increase weight of minimizing interconnection costs by modifying weight $\sim_c$, while keeping $\sim_j = 1$. Figure 3 depicts the obtained results for DC_j^{E2E}, $j = 1,2,3$ and the E2E interconnection costs, for six service requests (from Table II).

The fact that interconnection cost has higher priority changes GPMS mapping and consequently, deteriorates E2E performance. It should be noted that, for service requests 4, 5 and 6, class mapping remains the same when $\sim_c = 4$ and $\sim_c = 10$. This is the result of GPMS's decision to preserve the offered E2E performance, since there is no mapping that might offer a better cost-performance trade-off.

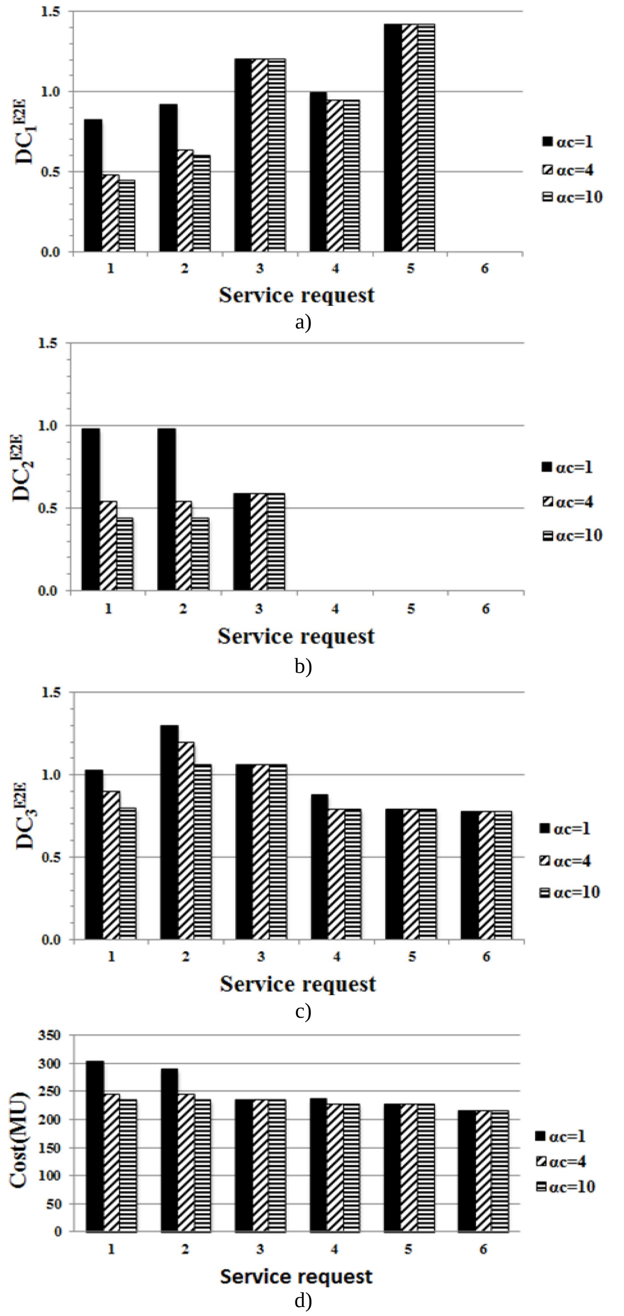

Fig. 3. The effect of $\sim_c$-modification on: a) delay; b) jitter; c) PLR; d) E2E interconnection costs.

Similarly, weights $\sim_j$ may also be modified to enforce class mapping closer to the perfect match. Such high level of flexibility in class mapping process delivers superior results over previously proposed P-CMS and 3PIP algorithms since GPMS contains the most features available in both algorithms with additional flexibility.

V. CONCLUSIONS

The important issue of service class mapping in interprovider QoS delivery scenarios can be addressed through the 3P-based GPMS algorithm. Comparative analysis of the GPMS and the two existing 3P-based schemes (P-CMS and 3PIP) has clearly demonstrated superiority of our proposal in terms of accuracy, flexibility, and possibility to support different business objectives. Bearing in mind GPMS flexibility, achieved by a set of adjustable parameters, it is possible to implement custom and yet controllable mapping, imposed by the 3P agent, as an impartial entity.

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