Connection-oriented Service Management in Provider Alliances: a Shapley Value Perspective

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I. Context[1]

In the context of cross-provider network service provisioning, the "Provider Alliance" concept has recently arisen as a necessary collaboration framework among providers willing to offer cross-provider connection-oriented services [1]. A possible provider alliance management solution for inter-AS Multi-Protocol Label Switching (MPLS) relies on the definition of a "service level" above a Path Computation Element (PCE)-based multi-domain control-plane as presented in [2].

In the provider alliance context, transit and edge service elements are offered and selected dynamically by providers to compose end-to-end tunnelling services, hence satisfing customer requests. Among the several parameters of a service element (or service level specification), the bandwidth can be considered as the main one. In the provider alliance solution proposed in [2], between the service element request (selection) and its provisioning (activation) there is a phase of instantiation that ends well if the resources announced with the service alement are actually available in the moment of the request. Operationally speaking, the service plane configuration of service elements'parameters shall be coordinated with a static resource reservation at the network plane.

A multi-domain distributed scheme for a cooperative optimization of inter-domain link reservation levels is presented in [3] (and in the sequel). The authors define the basis of an iterative distributed optimization process, run either in the control plane or in the management plane of the network, in which domains, cooperating in a coalition, calculate the optimal pattern of inter-domain traffic flow. The objective of the optimization process can be seen as a maximization of the sum of incomes of individual domains under the assumption that the income of a domain depends linearly on the amount of inter-domain traffic the domain injects into the network. As the objective function might prefer that a domain should rather transit than inject traffic, such an implicit distribution rule could lead to an unfair distribution of the total income. In fact, as a domain has no guarantee to gain any additional profit (in reality, it may even loose) there is no incentive to enter the coalition (or provider alliance).

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In order to close that gap, we completed the distributed cooperative optimization model with a mechanism of provably fair distribution of the coalition's income adopted from the theory of cooperative games [4]. It represents a further step toward the definition of novel business models for the future Internet.

II. Rationales

We are thus interested in an interconnection scenario in which multiple domains interact to optimize link capacity reservation levels, thus to improve their inter-domain routing, escaping a solution guided by unilateral and selfish choices toward a more effective global solution. An important outcome of the distributed optimization described in [3] is a configuration set of link reservation levels, which can be aggregated at the inter-domain (provider) scope.

When applied in the provider alliance context, we believe that the management agreement between providers shall rely on side payments since the multi-provider optimization can arise disparities. In fact, in order to reserve bandwidth for external connections for which no direct earning is obtained, a provider may need a form of economical incentive. Under this standpoint, it is indeed possible that, by reserving bandwidth for external connections, a provider grants earnings to its "peers" bigger than the earnings related to its own services.

It is thus needed to define a fair scheme for multi-provider income distribution that rewards a provider in a way that is not solely based on the generated traffic (Content provider behavior, see [6]) or absorbed traffic (Eyeball provider behavior, see [6]) but also accordingly to its *alliance transit contribution*, i.e., that takes into account how much a provider supports the services of the other providers allocating its network's resources.

III. A Shapley Value Perspective

The Shapley Value concept is a game theoretic solution for value imputation problems that offers interesting properties [5]. For this reason, it has been applied to very diverse fields [7]. The Shapley Value considers the strategic weight (importance) of each player in the alliance to share the alliance value, and satisfies desirable properties of individual fairness, efficiency, symmetry, additivity and null player modeling.

The Shapley value is calculated as follows: (i) consider all the possible permutations of the players (ii) for each permutation and each player, calculate the marginal contribution that the player grants if he joins the coalition formed by the predecessor players (iii) for each player, calculate the average of its marginal contributions on all the permutations.

The Shapley value can be used to assign the payoff (income) of a player (provider) as function of his marginal contribution to the coalition. Given that the marginal contribution that a player brings to a coalition (i.e., the alliance income related to its connection services) varies as a function of the players that already form the coalition, it is essential considering the order in which the player enters the coalition (or would enter if a coalition evaluates the opportunity of joining the new player).

In our context, each provider is modeled as a player. The marginal contributions to each possible subcoalition depends on the optimized reservation levels. The computation of this data is cumbersome, but not computationally complex. The subsequent computation of the Shapley Values is treatable for small networks, but increases fastly with the number of providers.

IV. Numerical experiments

In our experiments we compared imputation of the income of a multi-domain network generated by the proposed Shapley value based distribution with that generated by the original distribution (cf. [3]), where the whole income related to a demand is attributed to a domain that injects this demand into the network, and no domain receives income for transiting nor terminating the traffic. Note that value of the income is defined as equal to (depending linearly on) the total volume of demands that the coalition serves.

For example, in Fig. 1, we restrict our focus to an arbitrary destination node m_3 in a 7-domain networks; a number beside a link denotes the bandwidth reservation level. Considering these reservations, one can then easily compute the amount of traffic to node m_3 that every node either injects into the network, terminates or transits, hence the Shapley values can also be computed. Table I shows imputations generated by the two distributions (Shapley based and the original one) in context of the considered flow. Columns i, t and tr of the table show income components related to traffic that a domain injects and terminates, respectively. The last column $\sum$ denotes total imputation that a domain receives.

Observing Table I one can conclude that the original distribution is unfair – as there are significant unpaid volumes of traffic terminated by domain m_3 and transited through domains m_2, m_4 and m_5. The second part of Table I shows that the proposed Shapley value distribution schemes offers significantly fairer results, as domains are awarded for every type of their contribution in the total income (the 'x's mean that the Shapley value attributed to transit domain cannot be easily divided into components related to injecting and transiting of traffic).

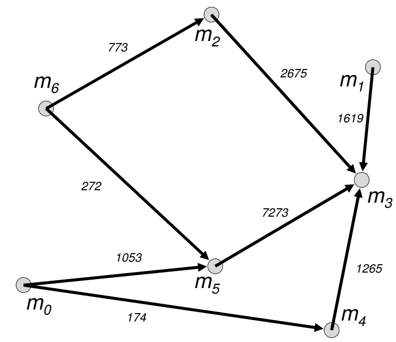

Fig. 1. Flow to domain m_3

	original distribution				Shapley distribution			
	i	t	tr	$\sum$	i	t	tr	$\sum$
m_0	1225	0	0	1225	408	0	0	408
m_1	1619	0	0	1619	809	0	0	809
m_2	1902	0	0	1902	x	0	x	1188
m_3	0	0	0	0	0	6010	0	6010
m_4	1091	0	0	1091	x	0	x	602
m_5	5948	0	0	5948	x	0	x	3408
m_6	1045	0	0	1045	323	0	0	323

TABLE I
FLOW m_3 RELATED INCOME DISTRIBUTION

V. Further work

As a further work we aim to refine the optimization decomposition method so as to allow a pro-active integration of the Shapley values. The idea is to control the amount of traffic volume a provider is allowed to inject within the alliance. In fact, it might be desirable to allow rewarding a provider's transit contribution directly with intra-alliance traffic injection ability by bounding the inter-provider throughput.

Such an integration of the Shapley value into the distributed optimization framework may reveal to be unfeasible for a number of technical reasons. One direction seems to compute good approximations of the Shapley Value. Using the existing mathematical formulation and exploiting the properties of the provider alliance game, other broader solution sets from the theory of cooperative games (e.g., the core) could allow to restrict to a few solutions close enough to the Shapley value.

References

[1] Stefano Secci, "Multi-Provider Service and Transport Architectures", Ph.D. thesis, Politecnico di Milano and Telecom ParisTech (2009).

[2] R. Douville, J.-L. Le Roux, J.-L. Rougier, S. Secci, "A Service Plane over the PCE Architecture for Automatic Multi-Domain Connection-Oriented Services", *IEEE Communications Magazine*, Vol. 46, No. 6 (2008).

[3] A.Tomaszewski, M.Pióro, M. Mycek, "A Distributed Scheme for Inter-Domain Routing Optimization", *Proc. DRCN'2007*, 2007.

[4] M. Mycek, S. Secci, M. Pióro, J.-L. Rougier, A. Tomaszewski, A. Pattavina, "Cooperative Multi-Provider Routing Optimization and Income Distribution", in *Proc. of DRCN 2009*.

[5] A.E. Roth, *The Shapley value, essays in honor of Lloyd S. Shapley*, Cambridge Univ. Press (1988).

[6] R. Ma et al., "Interconnecting eyeballs to content: a Shapley value perspective on ISP peering and settlement", in *Proc. of SIGCOMM 2008*.

[7] S. Moretti, F. Patrone, "Transversality of the Shapley value", *TOP*, Vol. 16, No. 1 (2008).