End-to-end Quality of Service in Pseudo-Wire networks*

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1. INTRODUCTION

Carrier-grade networks are complex systems that include several heterogeneous domains and support various types of services under specific Quality of Service (QoS) requirements. To tackle the problem of setting end-to-end connections across heterogeneous domains, the Pseudo-Wire architecture [1] allows to emulate some protocols (e.g. SDH, Ethernet, ATM, etc.) over MPLS. This emulation is achieved by encapsulation and decapsulation functions called adaptation functions. A path crossing heterogeneous domains must involve compatible functions so that datagrams are understandable by the source and target nodes (e.g. if Ethernet is encapsulated in MPLS by a node, it must be decapsulated by another).

When crossing several carriers, this heterogeneity issue becomes more pressing in order to support future collaborative inter-domain services. However, to support such services, the path computation problem has been mostly addressed under end-to-end (e2e) QoS requirements (e.g. delay ≤ 100 ms). In [2], the authors present algorithms solving this problem. To the best of our knowledge, the compatibility of adaptation functions has not been yet considered together with e2e QoS constraints.

This paper focuses on the computation of "feasible" (i.e. involving compatible adaptation functions) paths under QoS constraints. Section 2 is a first step towards the description of this problem and its complexity and section 3 sketches the possible approaches to solve it.

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2. E2E QOS IN PSEUDO-WIRE NETWORKS

2.1 Pseudo-wire network model

Consider a network with a set of nodes V, a set of links E and a set of protocols A. Each node v is associated to a set $\mathcal{Q}_v$ of QoS vectors whose components are QoS parameter values, a set of supported protocols A_v and a set of adaptation functions F_v. Let two protocols $a_m, a_n \in A$, $(a_m \rightarrow a_n) \in F_v$ and $(a_m \leftarrow a_n) \in F_v$ express respectively the encapsulation of a_m in a_n and decapsulation of a_m from a_n. $(a_m \rightarrow a_m) \in F_v$ denotes that a_m passively crosses v. In addition, we denote by $z(v, a_m \rightarrow a_n, q_v)$ the price of using the adaptation function $(a_m \rightarrow a_n)$ and the QoS vector q_v.

Feasible path. The goal is to compute a path from v_0 to v_t which involves compatible adaptation functions and meets QoS requirements. A path is a sequence of triples in the form (v, q_v, a_v), where $v \in V$, $q_v \in \mathcal{Q}_v$ is the chosen QoS vector, and $a_v \in A_v$ is the chosen protocol to cross the node v.

Let (v_0, q_{v_0}, a_0),(v_1, q_{v_1}, a_1),(v_2, q_{v_2}, a_2), $\ldots$, (v_m, q_{v_m}, a_m), (v_t, q_{v_t}, a_{m+1}) be a path. This path is *feasible* if $i)$ $a_0 = a_m$, $ii)$ each encapsulated protocol has been decapsulated before reaching v_t, and $iii)$ $a_k \in A_{v_k}$ for each $k \leq m$ and $(a_k \rightarrow a_{k+1}) \in F_{v_k}$ or $(a_{k+1} \leftarrow a_k) \in F_{v_k}$ for each $k \leq m$.

QoS vectors. Given a QoS vector q_v of a node v, we denote by $B(q_v)$, $D(q_v)$ and $L(q_v)$ the bandwidth, the delay and the packet loss respectively. Note that, further QoS parameters could be considered but these parameters represent all the possible mathematical types since bandwidth is concave, delay is additive and packet loss is multiplicative.

2.2 Problem definition

Given a path P_{v_0,v_t}, the objective function, denoted $Z(P_{v_0,v_t})$, is the sum of the prices of the selected adaptation functions and QoS vectors of the involved nodes. QoS constraints are formulated over e2e QoS requirements B_{min}, D_{max} and L_{max}.

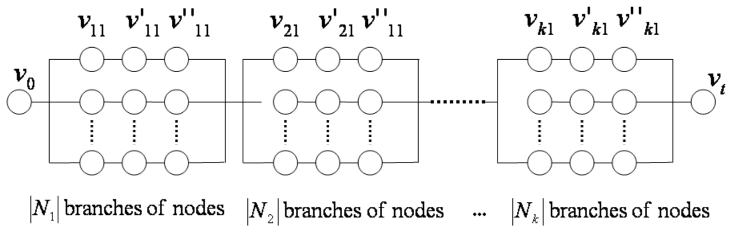

Figure 1: A series-parallel network built by reduction from the 2DMKP

$$\text{minimize } Z(P_{v_0,v_t})$$
$$s.t. \begin{cases} P_{v_0,v_t} \text{ is a feasible path} \\ \min\limits_{q_v \in P_{v_0,v_t}} B(q_v) \geq B_{min} \\ \sum\limits_{q_v \in P_{v_0,v_t}} D(q_v) \leq D_{max} \\ \prod\limits_{q_v \in P_{v_0,v_t}} (1 - L(q_v)) \geq 1 - L_{max} \end{cases} \quad (1)$$

In the decision version of problem (1) minimize $Z(P_{v_0,v_t})$ is replaced by $Z(P_{v_0,v_t}) \leq Z_{max}$.

2.3 Complexity

The decision version of the problem (1) is in NP: the compliance of a path with the QoS, feasibility and price constraints can be checked in polynomial time. To prove that the problem (1) is NP-hard, we provide a polynomial reduction from the decision minimization version of the *2-Dimensional Multiple choice Knapsack Problem (2DMKP)* as formalized by (2) to the decision version of the problem (1), as the minimization version of the 2DMKP is known to be NP-Complete [3].

$$\sum_{i=1}^{k} \sum_{j \in N_i} p_{ij} x_{ij} \leq M$$
$$s.t. \begin{cases} \sum_{i=1}^{k} \sum_{j \in N_i} w_{ij} x_{ij} \leq c \\ \sum_{i=1}^{k} \sum_{j \in N_i} w'_{ij} x_{ij} \leq c' \\ \sum_{j \in N_i} x_{ij} = 1, x_{ij} \in \{0,1\} \\ x_{ij} \in \{0,1\},\ i = 1,\ldots,k \ \ j \in N_i \end{cases} \quad (2)$$

Sketch of proof. Figure 1 is an illustration of a series-parallel network obtained from an instance of the problem (2) as follows: in order to represent possible adaptation functions for 2 given protocols a_1 and a_2, each object x_{ij} is transformed into 3 nodes v_{ij}, v'_{ij} and v''_{ij} in series, s.t. $F_{v_{ij}} = \{(a_1 \to a_2)\}$, $F_{v'_{ij}} = \{(a_2 \to a_2)\}$ and $F_{v''_{ij}} = \{(a_1 \leftarrow a_2)\}$. QoS vectors are obtained s.t. $\mathcal{Q}_{v_{ij}} = \mathcal{Q}_{v'_{ij}} = \mathcal{Q}_{v''_{ij}} = \{q_{ij}\}$, where $D(q_{ij}) = w_{ij}/3$ and $L(q_{ij}) = 1 - \exp^{-w'_{ij}/3}$; and the prices are s.t. $z(v_{ij}, a_1 \to a_2, q_{ij}) = z(v'_{ij}, a_2 \to a_2, q_{ij}) = z(v''_{ij}, a_1 \leftarrow a_2, q_{ij}) = p_{ij}/3$.

The sets of 3 nodes corresponding to objects in the same class N_i are disposed in parallel. Thus, each class N_i is transformed into $|N_i|$ sets of 3 nodes in parallel and the parts of the network corresponding to each class are disposed in series. The nodes v_0 and v_t are identified as the source and target nodes.

Let $Z_{max} = M$, $D_{max} = c$ and $L_{max} = 1 - \exp^{-c'}$, the reduction described above is linear in the parameters of the problem (2), and the problem obtained by this transformation, which is a a subset of instances of the decision version of the problem (1), is satisfied if and only if the problem (2) is satisfied.

3. RESEARCH AGENDA

To check the existence and compute a feasible path under QoS constraints, we will explore two approaches. First, we expect to design a dynamic programming algorithm. However, the efficiency of such an algorithm depends strongly on the set of adaptation functions of each node. The "feasibility" of a path does not exhibit an optimal structure in the general case. For example, considering three nodes v_0, v_1 and v_2, it is possible to create an instance of the problem (1) in which there are no feasible paths between v_0 and v_1 and between v_1 and v_2, but there is a feasible path between v_0 and v_2 via v_1. Thus, a classification of the instances of the problem (1) should be done to characterize the subset of instances on which a dynamic programing algorithm is efficient. In another approach, we plan to design general heuristics including meta-heuristics. Ant colony is naturally adapted to compute paths under constraints, the main challenge lies in the modeling of the path "feasibility".

In order to evaluate the behavior and the robustness of the designed algorithms, we aim to conceive a simulator capable of generating network topologies with realistic patterns of QoS and adaptation function distributions.

4. REFERENCES

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