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Application of Network Coding to the Network IP/MPLS within Node PE/P

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Abstract - We present in this paper the application of network coding to IP-based network within Multi Protocol Label Switching (MPLS) built with some sources and receivers. Particularly, the topology presented in this paper has node which is both source or Provider Edge (PE) and Provider (P). We integrate the coding node to this node named PE/P and apply the node-oriented strategy to solve the routing problem. We compare the delay between classical routing and routing with network coding.

Keywords - *MPLS, network coding, network calculus, load balancing.*

1. Introduction

The paper is concerned with the application of network coding IP/MPLS. Multi Protocol Label Switching (MPLS) [1] is a technology based on the propagation process with label within IP packet. The network can be designed only for the assumed initial conditions, but load and traffic characteristics vary in time. The network resources also vary because of the network topology changes. An important element of quality of service (QoS) offered is the minimum delay. The problems considered in this paper concern the network in different technology using the conception of logical paths, so the further consideration will be focused on the IP network within MPLS technologies.

Fault management mechanisms in MPLS networks are based on setting up the explicit Label Switched Path (LSP) [2]. In the case of congestion, the traffic can be directed to the path within network coding. The LSPs can be realized as static or partially dynamic [3]. The next section presents the network coding with network calculus for aggregated flows.

The proposed coding node strategy and the associated results applied in IP/MPLS are presented in section 3. Before the last section which concludes a brief discussion is provided.

2. Network coding

In this work, we consider the integration of network coding in the large class of networks providing quality of service (QoS) guarantees. In these networks, the data flows verify constraints of burst and maximal throughput and in return, the network provides guarantees in terms of end-to-end delays, minimal throughput to the data flows. We apply these works to IP/MPLS [4] networks.

2.1 Network calculus

Network calculus is a set of recent developments that provide deep insights into flow problems encountered in networking. To quantify the different parameters, we use the network calculus framework [5]. This theory allows to understanding better some fundamental properties of integrated services networks, scheduling and buffer or delay dimensioning. A detailed presentation of these concepts can be found in [5]. Other works on this subject are [6], [7].

2.2 Notations

The following definitions and results are directly extracted from [5].

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1) A data stream F transmitted on a link can be described by the cumulative function R(t), such that for any $y > x$, $R(y - x)$ is the quantity of the data transmitted on this link in time interval [x, y].

2) Let F be a data stream with cumulative function R(t). Let α be a wide-sense increasing function. We say that α is an arrival curve of F (or equivalently R) if for any $0 \leq t_1 \leq t_2$, $R(t_2) - R(t_1) \leq \alpha(t_2 - t_1)$. A common class of arrival curves are the affine functions $\gamma_{r,b}$ t) = r t + b for t > 0 and 0 otherwise.

3) The min-plus convolution of two functions X and Y is defined as $X(t) \otimes Y(t) = \inf_{0 \leq s \leq t}(X(s) + Y(t - s))$. It can be shown that α is an arrival curve of R if and only if $R \leq R \otimes \alpha$.

4) A leaky bucket controller is a device that analyzes the data on a flow R(t) as follows. There is a pool (bucket) of fluid (data) of size b. The bucket is initially empty. The bucket has a hole and leaks at a rate of r units of fluid (data) per second when it is not empty. Data that would cause the bucket to overflow is declared non-conformant; otherwise the data is declared conformant. A leaky bucket controller with leak rate r and bucket size b forces a flow to be constrained by the arrival curve $\gamma_{r,b}$.

5) Let R^{out} be the output flow of a node with one input flow R. We say that the node offers a service curve $\beta(t)$ to R if for any $t > 0$, $R^{out}(t) \geq R(t) \otimes \beta(t)$.

6) Assume a flow R(t), constrained by arrival curve $\alpha(t)$ traverses a system that offers a service curve of β. The output flow R^{out} is constrained by the arrival curve $\alpha \oslash \beta$, where $\alpha(t) \oslash \beta(t) = \sup_{i=1...n}\{R(t + v) - R(v)\}$.

7) The backlog, defined as $R(t) - R^{out}$ for all t, satisfies $R(t) - R^{out}(t) \leq \sup_{s>0}\{\alpha(s) - \beta(s)\}$. The virtual delay d(t), for all t, satisfies: $d(t) \leq h(\alpha, \beta)$, where $h(\alpha, \beta) = \sup_{s>0}\{\delta(s)\}$ where $\delta(s) = \inf\{\tau \geq 0 : \alpha(s) \leq \beta(s + \tau)\}$.

8) The Staircase Function $v_{T,\tau}$ used for T-periodic stream of packets of same size L which depend on variable delay τ is defined as :

$$v_{T,\tau}(t) = \begin{cases} \frac{t+\tau}{T} & if\ t > T \\ 0\ otherwise \end{cases} \quad (1)$$

where the interval $T > 0$ and the tolerance $0 \leq \tau \leq T$.

3. Application on the network IP/MPLS

3.1 Problem statement

The input flows, considered as a sequence of packets of same length L, are non-synchronized and they can be temporarily idle. Each flow verifies constraints of burst and throughput. The network is represented by the graph G = (V, E) where V is a set of nodes and E is a set of directed edges. The edges have a given capacity. The set of nodes is split into three categories: the source nodes Ingress-PE which generates the flows, the coding nodes PE/P which are able to perform network coding operations and receiver nodes egress-PE which receive and decode the combined flows.

In this section we consider a network built with IP/MPLS presenting node named PE/P, which is both a node source and transit-node. The main problem is then the routing on the link from this node.

We propose to integrate coding node to the PE/P and apply the node-oriented strategy [6]. This section aims at determining the service offered by the network to the input flows towards the output flows. In others words, we aim at defining a transfer matrix M whose entries are service curves.

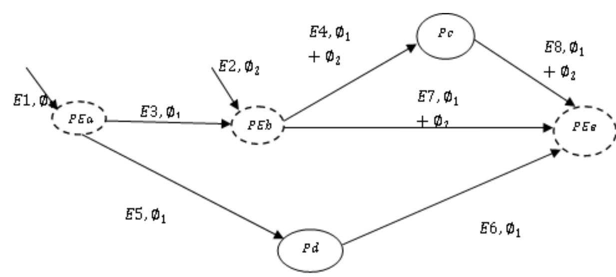

Fig. 1 Topology named NC_MPLS.

Let us consider a network represented by an acyclic directed graph G = (V, E) with a vertex set $V = \{v_1 . . . v_m\}$ and an edge set $E = \{e_1, . . . , e_p\}$. We allocate to each edge e_i a capacity C_{ei}. We consider s vertex among m as source nodes and r is receiver node. We assume that the source nodes generate some flows R_i, i = 1,...,k, respectively constrained by an arrival curve α_i. Each source node offers a given service curve to its flows towards its different output links

A coding node with input links and output links combines the input flows to produce the output flows following a linear network code determined a priori. We consider that

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its input flows $R_1 \dots R_k$ are respectively constrained by the arrival curves $\alpha_{1,in}, \dots, \alpha_{k,in}$. It provides to its input flows a service curve towards the output flows. Note that this service curve can be the constant function equal to 0.

Let $\beta_{i,j}$, $i = 1, \dots, k$ and $j = 1, \dots, s$ be the service curve offered by the coding node to the input flow R_k towards the j-th output flow $R^{k,out}$.

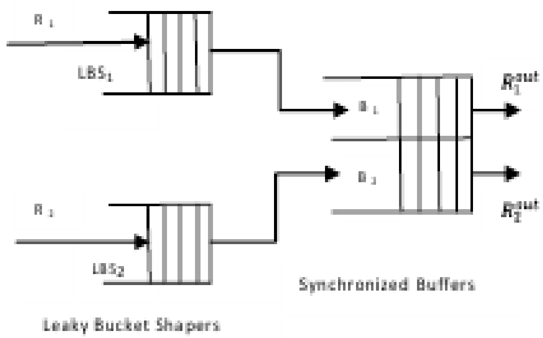

Fig. 2 Architecture of the coding node.

3.2 Application on the example

The topology of the example considered in this section is presented on the figure 1 above. The network provides 5 nodes with 2-ingresses and 1-egress and 8 links between them. We have two sources *ingress-PEa* and ingress-*PEb* and one receiver egress-*PEe*; the coding node *PEb* is implementing with two leaky bucket shapers LBSs and two FIFO as in the figure 2.

The two input flows and the output flow are respectively represented by their cumulative functions R_1, R_2 and R_1^{out} and R_2^{out}. The input flows are composed of packets of length L.

Recall that p, k and n represent respectively the number of edges, input flows, and output flows. We will say that an edge i (or a flow) is connected to an edge j (or a flow) if the head of the edge i is the tail of the edge j. Let us now define the following matrices:

Let $A = (a_{i,j})i=1,\dots,k;j=1,\dots,p$ be defined as follows. If the flow R_i is connected to the flow on the edge j, then $a_{i,j} = \beta_{i,j}$ the service curve offered , else $a_{i,j} = 0$.
For the network of the Figure 1, we have:

$$A = \begin{bmatrix} 0 & 0 & \beta_{a3} & 0 & \beta_{a5} & 0 & 0 & 0 \\ 0 & 0 & 0 & \beta_{b4} & 0 & 0 & \beta_{b7} & 0 \end{bmatrix}$$

Let $F = (f_{i,j})i=1,\dots,p;j=1,\dots,p$ be the adjacency matrix defined as follows. If the edge i is connected to the edge j then $f_{i,j} = \beta_{i,j}$ the service curve offered, else $f_{i,j} = 0$.
For the network of the Figure 1, we have:

$$F = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \beta_{34} & 0 & 0 & \beta_{37} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \beta_{48} \\ 0 & 0 & 0 & 0 & 0 & \beta_{56} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Since the graph G is acyclic, the adjacency matrix can be represented as a strict upper-triangular matrix. It is then nilpotent and we can compute the matrix $I + F + F^2 + F^3 + \dots$ which indicates the states of the input flows in the network. For the network of the Figure 1, $I+F+F^2+F^3+\dots$ is equal to:

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & \beta_{34} & 0 & 0 & \beta_{37} & \beta_{34} \otimes \beta_{48} \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & \beta_{48} \\ 0 & 0 & 0 & 0 & 1 & \beta_{56} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Let $B = (b_{i,j})i=1,\dots,p; j=1,\dots,n$ be defined as follows. If the edge i is connected to the output flow R_j^*, then $b_{i,j} = \beta_{i,j}$ the service curve offered, else $b_{i,j} = 0$. For the network of the Figure 1, we have:

$$B = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & \beta_{6\theta_1^*} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \beta_{7\theta_2^*} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \beta_{8\theta_2^*} \end{bmatrix}$$

Following the similar construction of the transfer matrix presented in [5], we can obtain the transfer matrix

$$M = A \times (I + F + F^2 + \cdots) \times B$$

$$[\emptyset_{1,2}^*] = [\emptyset_1, \emptyset_2] \oslash M \quad (2)$$

We can then obtain the values of $\emptyset_{1,2}^*$ by applying Eq (2). This simple example demonstrates the interest of the network coding in this context. Indeed, compared to a traditional approach (with two multicast sources and one receiver) multiplexing the flows, the network coding allows to improve the guaranteed throughput if we

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consider that the edge 7 has a finite capacity. In this case, the deterministic bound on the end-to-end delays is also improved.

For the network of the Figure 1, M is equal to:

$$\begin{bmatrix} \beta_{a5} \otimes \beta_{56} \otimes \beta_{60'} & \beta_{a3} \otimes \beta_{37} \otimes \beta_{70'} & \beta_{a3} \otimes \beta_{34} \otimes \beta_{48} \otimes \beta_{80'} \\ 0 & \beta_{b7} \otimes \beta_{70'} & \beta_{b4} \otimes \beta_{48} \otimes \beta_{80'} \end{bmatrix}$$

The same strategy will be applied on the receiver node Egress-*PEe*, and the 3 LBSs with 3 FIFO can be implementing in this node. The table 1 below can provide the result of the decoding process. We then see that the delays will be improved.

Table 1: Comparison of delays

Delay	***Classical routing***	***Routing with network coding***
PEb	β_{a3}	$\beta_{a3} \otimes \beta_{34} \otimes \beta_{48} \otimes \beta_{80'}$
PEb	β_{b4}	$\beta_{b4} \otimes \beta_{48} \otimes \beta_{80'}$

4. Conclusions

This paper has provided an improvement solution for introducing the network coding in networks with PE/P node in IP/MPLS. A coding strategy was proposed to obtain minimal upper bounds on the rate of the output flow without excessive buffering and delays. The method is based on a transfer matrix whose entries are service curves. This work can be extended by introducing the differentiated service with MPLS by separating the different lengths of the packets.

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