

Multicast Tree in MPLS Network

Ali Boudani and Bernard Cousin

IRISA/INRIA Rennes,
Campus Universitaire de Beaulieu,
Avenue du Général Leclerc
35042 Rennes, France
{aboudani, bcousin}@irisa.fr

Abstract. In this paper, we study multicast tree construction in MPLS network. We discuss the difficulty in combining multicast and MPLS in a network. We describe some MPLS proposals for the multicast traffic and we justify the need for defining a new protocol. Thereafter we propose MMT, the MPLS Multicast Tree protocol, which uses MPLS LSP¹ between multicast tree branching nodes in order to reduce the routing states and to increase scalability. We present improvements to MMT protocol and we evaluate it in term of scalability and efficiency. Finally, we present simulation results to validate our evaluation and we conclude that the MMT protocol seems promising and well adapted to a possible implementation of multicast traffic engineering in the network.

1 Introduction

Increasing the efficiency of Internet resources utilization is very important. Several evolving applications like WWW, video/audio on-demand services, and teleconferencing consume a large amount of network bandwidth. By reducing the number of packets transmitted across the network, the multicast service essentially increases the QoS given to users due to the additional available bandwidth in the network, which increases network performance. MPLS (Multi-Protocol Label Switching) [1] as a traffic engineering tool has emerged as an elegant solution to meet the bandwidth management and service requirements for next generation Internet Protocol (IP) based backbone networks. MPLS is an advanced forwarding scheme that extend routing with respect to packet forwarding and path controlling. Packets are classified easily at domain entry and rerouted faster in the case of link failures. Explicit routes are easily constructed and packets may follow these explicit routes instead of following the traditional shortest route [2]. Once a packet is assigned to a FEC (Forwarding Equivalence Class), no further header analysis is done by subsequent routers in the same MPLS domain. An MPLS header, called label, is inserted for each packet within an MPLS domain. An LSR (Label Switching Router) will use the label as the index to look up in the forwarding table. The packet is processed as specified by the forwarding table entry. The incoming label is replaced by an outgoing label, and the packet is switched toward the next LSR. Before a packet leaves an MPLS domain, its MPLS header is removed. The paths between the ingress LSRs (at the domain entry) and egress

¹ Label switched Path.

LSRs (at the domain exit) are called label-switched paths (LSPs). MPLS uses some signaling protocol such as Resource Reservation Protocol (RSVP) [3] or Label Distribution Protocol (LDP) [4] to set up LSP.

Multicast and MPLS are two complementary technologies. Merging these two technologies, making multicast trees built on top of MPLS networks will enhance the network performance and present an efficient solution for multicast scalability and control overhead problems. Multicast attempts to reduce network bandwidth usage, while MPLS attempts to provide users with needed bandwidth in an appropriate switched-like manner.

The remainder of this paper is organized as follows. In Section 2, we present MPLS proposals for multicast traffic and we justify the need for defining a new protocol. In Section 3, we describe the MMT protocol (MPLS Multicast Tree) and its extension the MMT2 protocol, which use MPLS LSPs between the multicast tree branching node routers in order to reduce forwarding states and enhance scalability. In Section 4, we evaluate our proposals in terms of scalability and efficiency and we present some simulation results evaluation. Section 5 is a summary followed by a list of references.

2 Merging MPLS and multicast

MPLS can be deployed in a network to forward unicast traffic through explicit routes and multicast traffic by using explicit trees². But multicast traffic has specific characteristics due to the nature of the multicast routing protocols [5]. Indeed, the multicast routing is based on multicast IP address and this is why it is very difficult to aggregate multicast traffic since receivers belonging to the same group can be located at multiple localizations.

A framework for IP multicast deployment in an MPLS environment is proposed in [5, 6]. Issues arising when MPLS techniques are applied to IP multicast are overviewed. Following characteristics are considered: aggregation, flood and prune, co-existence of source and shared trees, uni/bi-directional shared trees, encapsulated multicast data, loop free ness and RPF check. The pros and cons of existing IP multicast routing protocols in the context of MPLS are described and the relation to the different trigger methods and label distribution modes are discussed. The framework did not lead to the selection of one superior multicast routing protocol but it concluded that different IP multicast routing protocols could be deployed simultaneously in the Internet. It should be noted that the multicast tree structure requires P2M (point-to-multipoint) LSP or even MP2MP (multipoint-with-multipoint) LSP establishing. In the current architecture of MPLS, only point-to-point LSP were studied. MPLS does not exclude other types of LSP, but no mechanism was standardized so far.

MPLS labels support the aggregation of trees but does not solve the problem completely. Indeed, algorithms should be designed to aggregate unicast flows with multicast flows and also aggregate multiple multicast flows together. Unfortunately, the current studies on multicast aggregation are limited to the aggregation of the routing states in each router rather than to the LSP aggregation. For further details, we recommend the reader the broad literature which exists in this subject, or to refer to our work ([7], chapter 4 of [8]). In this paper, we are concerned

² An explicit tree can be built through policies and explicit routes instead of topology.

mainly in two MPLS multicast routing protocols : PIM-MPLS [9] and Aggregated multicast [10].

2.1 PIM-MPLS

Using PIM-SM *join* messages [11] to distribute MPLS labels for multicast routes is proposed in [9] (called hereinafter PIM-MPLS). A piggy-backing methodology is suggested to assign and distribute labels for multicast traffic for sparse-mode trees. The PIM-SM *join* message should be expanded to carry an MPLS label allocated by the downstream LSR. Modifications to PIM-SM make this proposal not easily accepted by working groups dealing with multicast in the IETF. In plus, MPLS is not used with all its efficiency as a traffic engineering tool since the multicast tree still constructed using the RPF tree checking without constraints.

2.2 AGGREGATED-MULTICAST

The key idea of aggregated multicast [10] is that, instead of constructing a tree for each individual multicast group in the CORE network, multiple multicast groups may share a single aggregated tree to reduce multicast state and, correspondingly, tree maintenance overhead at the CORE network. In this proposal there is two requirements: (1) original group addresses of data packets must be preserved somewhere and can be recovered by exit nodes to determine how to further forward these packets; (2) some kind of identification for the aggregated tree which the group is using must be carried and transit nodes must forward packets based on that. To handle aggregated tree management and matching between multicast groups and aggregated trees, a centralized management entity called tree manager is introduced. In group to aggregated tree matching, complication arises when there is no perfect match or no existing tree covers a group (leaky matching). The disadvantage in leaky matching is that a certain amount of bandwidth is wasted to deliver data to nodes that are not involved for the group.

3 The Multicast MPLS Tree Proposal

In [12], we proposed the MMT protocol (MPLS Multicast Tree). The MMT protocol construct a multicast tree by considering only the branching node routers on this tree. By limiting the presence of multicast routing states to branching node routers, the MMT protocol converts multicast flows into multiple quasi-unicast flows. In MMT, instead of constructing a tree for each individual multicast channel³ in the CORE network, one can have several multicast channels sharing branches of their trees. The unicast LSP are used between the branching node routers of the multicast tree. By using this method, we reduce the information quantity to be memorized in routers and we ensure scalability.

³ A channel is a group identified by the couple (S, G) where S is the source address and G is the group address.

3.1 MMT and IP multicast protocols

In comparison with the IP multicast, the MMT protocol has several advantages which are detailed as follows:

- It uses a network information manager system, called hereinafter NIMS⁴, to ensure the multicast traffic engineering in the network : a NIMS keeps all necessary information on LSP. All sources and all destinations of various multicast groups as well as the bandwidth associations are known. The NIMS is informed directly of any change of topology of the network (LSP or routers failure) and of any change of membership of a group destination. A tree is calculated using this NIMS and transmitted thereafter on the network.
- It simplifies LSP setup : there is not no need to create and maintain P2MP or MP2MP LSP. Instead, a tree can be broken up and its branches associated with P2P LSP. So P2P LSP are used for the transmission of multicast traffic.
- It makes easier the aggregation of multicast flows : each branch of a multicast tree can be aggregated with other unicast traffic which share the same ingress and egress LSR.
- It is inter-operable with other multicast protocols : the protocol can be limited to only one domain (typically the CORE network). In other domains, traditional multicast routing protocols can be used. Once transmitted in MPLS domain, multicast packets will be forwarded on paths constructed by the MMT protocol mechanisms.

In the following Section, we present the role of the NIMS in charge to calculate the tree and to collect link state informations and group memberships besides running group to tree matching algorithm. Thereafter we present the MPLS tree construction as well as new LSP construction.

3.2 Multicast MPLS tree construction by the NIMS

In MMT, each domain contains a NIMS for each group, charged to collect *join* and *leave* messages from all group members in that domain. The NIMS is elected through a mechanism similar to the one used to elect the RP router⁵ in PIM-SM [11]. After collecting all *join* messages, the NIMS computes the multicast tree for that group in the domain (It uses the Dijkstra's algorithm with constraints). The computation for a group means discovering all branching node routers for that group. The NIMS sends then *branch* messages to all branching node routers to inform them about their next hop branching node routers. On receiving this message, a branching node router creates a multicast forwarding state for the multicast channel. Once branching node routers and their next hops are identified, packets will be sent from a branching node router to another until reaching their destination.

⁴ It is conform with the IETF recommendations for the multicast MPLS. But the NIMS is a critical point of failure. A certain redundancy of the NIMS can ensure the survivability of the service. A certain distribution of the NIMS is possible. We do not treat it here : (1) it would unnecessarily complex our analysis;(2) ideally the distribution is independent of the multicast traffic engineering.

⁵ The NIMS can be different within the same domain for each channel (S, G) . Thus, we can talk about load balancing, distribution of NIMS service and increased survivability of the system.

Already established MPLS LSPs are used between multicast tree branching node routers in order to reduce forwarding states and enhance scalability. When a multicast packet arrives to the ingress router of an MPLS domain, the packet is analyzed according to its multicast IP header. The router determines who are the next hop branching node routers for that packet. Based on this information, multiple copies of the packets are generated and an MPLS label is pushed on the multicast packet according to next hop branching node router. When arriving to a next hop branching node router, the label is popped off and again the same process is repeated. This process should be repeated until the packet arrives to its destination (see Fig.1). When arriving to a LAN, the packet unlabeled can be delivered by conventional multicast protocols according to IGMP [13] informations.

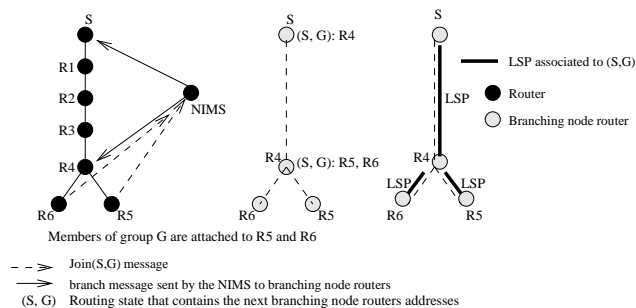


Fig. 1. Multicast MPLS tree construction.

In our approach we will use the same MPLS label for multicast traffic that follows the same path than unicast traffic. Other approaches use different labels for multicast and unicast traffic which mean the need of encoding techniques and additional overheads in routers.

Edge Router Multicasting is a proposal for the multicast in an MPLS network introduced in [14]. It is based on the same principles as the MMT protocol. However, ERM limits the branching node points of the multicast tree to EDGE routers of MPLS domains. Packets are sent on branches using established MPLS tunnels between the EDGE routers through the CORE routers. Consequently, as in MMT, the multicast LSP construction, the multicast flows association and the multicast traffic aggregation are transformed into simple unicast problems.

In ERM, contrary to MMT, the reservation of the bandwidth for multicast flows is not treated. Moreover, the link stress around the EDGE routers increases since the packet duplication is only allowed in the EDGE routers. The ERM characteristics make it not recommendable (as concluded in similar approach of MPLS Multicast VPN [15]). A comparison between MMT and ERM can be found in [8].

3.3 Improving MMT : the MMT2 protocol

In this section, we suppose that some routers in the network can not support mixed routing⁶. We solve the mixed routing problem by using a double level of labels while preserving the MMT protocol principles of operation. The label of the lower level is a unique label representing a channel (S, G) . A label (belonging to a label interval reserved to the MMT2 protocol) is allotted to the channel (S, G) at the reception by the NIMS of the join messages for this channel. This label identifies the channel in the domain managed by the NIMS. This label could be different from one domain to another. The NIMS informs all branching node routers about this label as well as the labels corresponding to the next branching node routers for this channel. An extension of the *branch* message is necessary to carry the new information. The label corresponding to the channel (S, G) is added to the multicast packet at the domain entry, the LSR *ingress* of the domain adds also the labels of the higher level which corresponds to the next branching node routers for the channel. In intermediate routers, those who are not branching node routers, the packet is analyzed according to the entering label placed in top of the label stack, label which will be replaced by an outgoing label as in unicast MPLS. When the packet arrives to an intermediate branching node router, the label of the higher level is removed, the label identifying of the channel is treated and the new labels which corresponds to the next branching node routers are added (*cf.* figure 2). This operation is repeated until the arrival of the packet to the *egress* router. All the labels are thus popped and again the packet is sent towards the *ingress* routers of other domains or directly towards the destinations belonging to sub-networks of the *egress* routers.

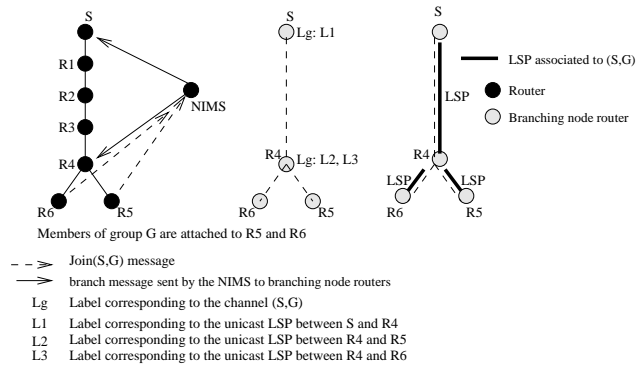


Fig. 2. Multicast MPLS tree construction with the MMT2 protocol.

3.4 The MMT2 protocol and aggregated trees

Due to the limited number of labels, MMT2 calculates only the aggregated trees. We choose, like *Aggregated multicast*, that two channels will be associated to the

⁶ We mean by mixed routing the coexistence of L2/L3 forwarding schemes in a router. For example, it is the case of router $R4$ in figure 1.

same aggregated tree in a domain if the tree calculated for the first channel has exactly the same branches as the tree calculated for the second channel in that domain. Thus, the NIMS can associate several channels to the same aggregated tree, in order to limit the use of labels in the domain and to reduce even the routing states to be stored at the branching node routers. In the next section, we evaluate the approach in term of scalability (multicast routing states reduction) and efficiency (the packet header processing time in routers and the cost of the multicast tree).

4 Evaluation of MMT protocol

In this section, we compare MMT and its extension MMT2⁷ with different multicast MPLS protocols, in particular PIM-MPLS [9] and *Aggregated multicast* [10]. In our simulations, PIM-MPLS refers to the simulator described in [16] where PIM-SM source specific was chosen as the multicast routing protocol. We simulate the MMT protocol with NS [17] to validate the basic behavior of the approach and its efficiency to reduce the number of routing states, to decrease the packet header processing time and to lower the cost of the trees. Indeed, MMT uses on one hand the best paths tree⁸ and uses on other hand the MPLS fast label switching technique in routers.

4.1 Scalability

Since only branching node routers are considered in a multicast tree, it is obvious that our approach reduce the size of routing tables. An MPLS domain can be a transit domain for a channel where neither source nor destinations are present in the domain. A tree having one or more branching nodes in a domain is called BT (*Branched Tree*). A tree with only one path in the domain where no branching node appears in the tree is called OPT (*One Path Tree*). The table 1 represents the average number of routing states in routers in both case : BT trees of transit with branching nodes and OPT trees of transit without branching nodes.

Protocol/ Tree	PIM-MPLS	<i>Aggregated multicast</i>	MMT	MMT2
BT	$\bar{n}_T * T$	$\bar{n}_{T_{agg}} * T_{agg}$	$\bar{n}_{MMT} * T$	$\bar{n}_{MMT-agg} * T_{agg}$
OPT	$\bar{n}_T * T$	$\bar{n}_{T_{agg}} * T_{agg}$	$2 * T$	$2 * T_{agg}$

Table 1. The average number of routing states in routers.

Let T represent the number of multicast trees present in the network, \bar{n}_{MMT} the average number of branching node routers on the trees by using the MMT protocol, $\bar{n}_{MMT-agg}$ ⁹ the average number of branching node routers on the trees

⁷ We consider only aggregated trees.

⁸ The best paths tree, calculated by the NIMS, coincides with the shortest paths tree in absence of any traffic engineering constraints.

⁹ In the remainder of this evaluation, we consider that \bar{n}_{MMT} and $\bar{n}_{MMT-agg}$ include also the states present in the sources and the destinations.

by using the protocol MMT2, \bar{n}_T the average number of routers on the multicast trees by using a traditional multicast routing protocol, T_{agg} is the number of aggregated trees of *Aggregated multicast*, $\bar{n}_{T_{agg}}$ is the average number of routers on the aggregated tree. These values satisfy the following relation :

$$T \geq T_{agg},$$

$$\bar{n}_T \geq n_{MMT}, n_{MMT-agg},$$

$$\bar{n}_{T_{agg}} \geq n_{MMT-agg},$$

and

$$\bar{n}_T, \bar{n}_{T_{agg}} \geq 2.$$

It is obvious according to table 1 that MMT presents better performances than PIM-MPLS. In the case of OPT trees, the number of routing states for MMT in the intermediate routers in the network is equal¹⁰ to 0 and thus MMT has better performances compared to *aggregated multicast*. Indeed, less memory usage in the tables, thus less processing required scanning tables. In the case of BT trees, the number of routing states for the MMT protocol is not always lower than that *Aggregated multicast*. Indeed, the MMT protocol present of better performances on *Aggregated multicast* only when $n_{MMT} * t < \bar{n}_{T_{agg}} * T_{agg}$. Let's take the following example : According to [18, 19], the vBNS network is composed of 43 routers of which 16 are CORE routers. The 43 routers participate in distributing multicast traffic. In the example presented [18], a set of 2500 multicast channels are present in the network. These 2500 trees are aggregated in 1150 trees. Thus, $\bar{n}_{T_{agg}}$ must be larger than $n_{MMT} * \frac{2500}{1150} \approx 2.2 * n_{MMT}$ to have MMT better than *Aggregated multicast*. As we presented in chapter 2 of [8], the number of branching node routers on a tree is very small (about 8% of the number of routers of the tree). We deduce that n_{MMT} at maximum can reach ≈ 4 . If the value of $\bar{n}_{T_{agg}}$ exceeds $n_{MMT} * \frac{T}{T_{agg}} \approx 9$, MMT presents then better performances. Thus, it is possible that MMT reduces more than *Aggregated multicast* the size of the multicast routing tables in the routers. Finally, according to table 1, MMT2 presents better performances compared to all the other protocols. To validate our evaluation, we consider the 3 networks: MCI¹¹ (18 nodes in the CORE network), Abilene (11 nodes in the CORE network) and NSFNET (14 nodes in the CORE network), and we calculate the number of trees aggregated for 5000 trees. We consider that only one node is attached to each CORE node and this node may be either source either destination. The number of members for each group is between 2 and 10 for the Abilene network, 2 and 12 for network NSFNET and 2 to 16 for MCI network.

Figures 3, 4 and 5 present the average number of routing states in a router for the 3 networks : Abilene, MCI and NSFNET.

We notice that the MMT2 protocol has advantages over all the other protocols. We also notice that PIM-MPLS has the worst results. For MMT and *Aggregated multicast*, we notice that MMT has advantages over *Aggregated multicast* in MCI network but it is very bad with the Abilene network. Starting from a certain number of trees, *Aggregated multicast* has more advantages on MMT in NSFNET

¹⁰ We do not consider the routing states in the two EDGE routers source and destination in the network.

¹¹ Note that MCI developed the vBNS+ network.

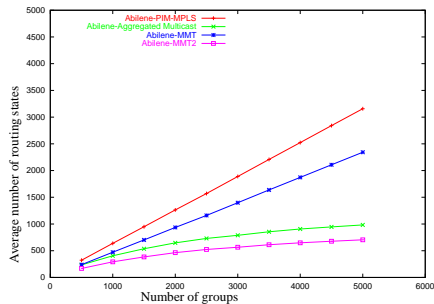


Fig. 3. Abilene.

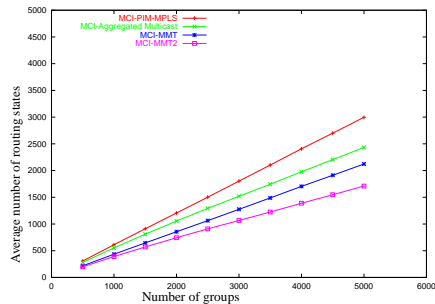


Fig. 4. MCI.

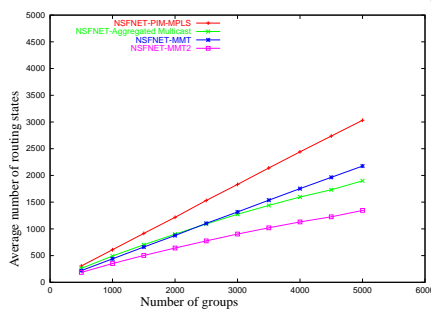


Fig. 5. NSFNET.

Fig. 6. Average number of routing states in a router for the 3 networks Abilene, MCI et NSFNET for the different protocols.

network. Indeed, the Abilene network contains only 11 node : if the number of members in a group is large, then all routers in the CORE are possible branching node routers¹². If the number of members in the groups is small, the $\frac{T}{T_{agg}}$ ratio becomes large and thus the MMT protocol is not appropriate for this kind of topology. In all the cases, the MMT2 protocol reduces better than other protocols the size of the routing tables.

4.2 Packet header processing in routers

The delay time for tree construction and the packet transmission delay are two important parameters to study. In the three protocols MMT, MMT2 and *Aggregated multicast*, a control entity receives the join messages, calculates¹³ the tree for each channel and starts association between labels and channels. The tree construction delay time is thus the same for these three protocols¹⁴. However, in the

¹² Note that we consider the routing states in the source and all the destinations.

¹³ Let us note that the calculation of random million trees for the Abilene Network in a control entity can take a computing time of about 43 seconds. The algorithm to associate a channel to a tree was tested on Linux *P4 2.4 Ghz*.

¹⁴ But an advantage for MMT and MMT2 is that the LSP *unicast* are used for the multicast traffic.

case of a traditional multicast routing protocol, each router between the ingress and the egress must contain a routing state for each multicast tree. Let us consider $t_{Trait}(Ri)$, called hereinafter processing time, the time necessary to treat a packet in a router Ri and to thereafter retransmit it towards the outgoing interface. We will compare the total packet processing time $t_{Traitg} = \Sigma t_{Trait}(Ri)$ for the protocols PIM-MPLS, *Aggregated multicast*, MMT and MMT2. The packet processing time, t_{Trait} , can be calculated by the following formula :

$$t_{Traitg} = \Sigma t_{Trait}(Ri) = t_L + t_{FA} + t_R,$$

where t_L is the packet transmission time on links between the source and the receiver on the multicast tree, t_{FA} is the latency of the packet in the queue of the routers, and t_R is the packet processing time in the routers. Let us consider $A = t_L + t_{FA}$, a constant which does not change with the different protocols¹⁵.

PIM-MPLS : We note that $t_R = \bar{n}_T * t_{MPLS \bar{multicast}}$, so :

$$t_{Traitg} = A + \bar{n}_T * t_{MPLS \bar{multicast}},$$

where \bar{n}_T is the average number of routers on a multicast tree and $t_{MPLS \bar{multicast}}$ is the average time to traverse the label table. $t_{MPLS \bar{multicast}}$ depends on the number of trees passing by a router.

MMT : In MMT, only branching node routers keep multicast routing states. In these routers, the MMT protocol seeks to find the corresponding *FEC* in the label table. All the other routers on the tree use the unicast MPLS routing tables to forward packets. So :

$$t_{Traitg} = A + (\bar{n}_T - n_{MMT}) * t_{MPLS \bar{unicast}} + n_{MMT} * (t_{MPLS \bar{multicast}}).$$

$t_{MPLS \bar{unicast}}$ is the average time to traverse the unicast table of labels.

$$\begin{aligned} \delta_{MMT, PIM-MPLS} &= \bar{n}_T * (t_{MPLS \bar{unicast}} - t_{MPLS \bar{multicast}}) \\ &+ n_{MMT} * (t_{MPLS \bar{multicast}} - t_{MPLS \bar{unicast}}) \\ &= (\bar{n}_T - n_{MMT}) * (t_{MPLS \bar{unicast}} - t_{MPLS \bar{multicast}}). \end{aligned}$$

The value of n_{MMT} is smaller in general than the value of \bar{n}_T . Moreover, with the increase in the number of channels, the value of $t_{mpls \bar{multicast}}$ grows too. The value of $t_{mpls \bar{unicast}}$ becomes smaller than the value of $t_{mpls \bar{multicast}}$ and $\delta_{mmt, pim-mpls}$ takes negative values. We conclude that the MMT protocol has advantages over the PIM-MPLS protocol and all other protocols using the same type of construction of MPLS multicast trees. Note that according to [20], a Juniper T640 router can treat a package in $10^{-9}s$ and the saving of time resulted from packets processing can be translated into a higher flow and a capacity to forward a higher number of packets.

¹⁵ A network with symmetrical links.

Aggregated multicast : As in the case of PIM-MPLS we note that :

$$t_R = n_{T_{agg}}^- * t_{MPLS_{agg}}^-,$$

Then :

$$t_{Traig} = A + n_{T_{agg}}^- * t_{MPLS_{agg}}^-,$$

where $t_{MPLS_{agg}}^-$ is the average time to traverse the table of labels present in the routers after use of the protocol *Aggregated multicast*. We obtain as follows:

$$\begin{aligned} \delta_{MMT, Aggregated\ multicast} &= (n_T^- - n_{MMT}^-) * t_{MPLS_{unicast}}^- \\ &+ n_{MMT}^- * t_{MPLS_{multicast}}^- \\ &- n_{T_{agg}}^- * t_{MPLS_{agg}}^-. \end{aligned}$$

It is not easy to make approximations with this formula. Indeed, searching in a routing table is not linear : it can be sometimes logarithmic curve with the use of the various techniques of searching [21]. The $t_{mpls_{agg}}^-$ value also depends on the reduction ratio of the multicast trees. Moreover, in comparison with MMT2 protocol, it is easy to conclude¹⁶ that $\delta_{mmt2, aggregated\ multicast}$ often takes negative values, which enables us to conclude that protocol MMT2 has advantages on the protocol *Aggregated multicast* in term of packet processing time.

$$\begin{aligned} \delta_{MMT2, Aggregated\ multicast} &= (n_{T_{agg}}^- - n_{MMT_{agg}}^-) * t_{MPLS_{unicast}}^- \\ &+ n_{MMT_{agg}}^- * t_{MPLS_{agg}}^- \\ &- n_{T_{agg}}^- * t_{MPLS_{agg}}^- \\ &= (n_{T_{agg}}^- - n_{MMT_{agg}}^-) * (t_{MPLS_{unicast}}^- - t_{MPLS_{agg}}^-). \end{aligned}$$

Let us notice that it is very difficult to simulate the exact values of the total processing time of a multicast packet. Indeed, this processing depends on the size of the routing table and the technique of searching used to find an entry in this table. Thus, we can be satisfied by making a simple comparison between PIM-SM and PIM-MPLS. Indeed, according to [22], MPLS can reduce 25% the packet processing time and since the two protocols PIM-SM and PIM-MPLS have exactly the same number of routing states, the comparison becomes easy by supposing that the packet processing time of a unicast and multicast packet is the same¹⁷. The figure 7 represents the end-to-end delays minimum, maximum and average of the trees when the number of receivers varies from 2 to 16 for the two protocols PIM-SM and PIM-MPLS in the MCI network. We carried out 100 simulations for each value from 2 to 16. The value presented in the graphs is the average value for the 100 simulations. We deduce that using MPLS reduce the end-to-end delay time for the various destinations.

4.3 Tree cost

The MMT, MMT2 protocols use the best paths tree. In the absence of constraints, the best paths tree is the shortest paths tree. *Aggregated multicast* uses the shortest paths tree while PIM-MPLS uses the reverse shortest paths tree. Note that the

¹⁶ Since $(n_{T_{agg}}^- - n_{MMT_{agg}}^-)$ is always ≥ 0 and $(t_{mpls_{unicast}}^- - t_{MPLS_{agg}}^-)$ is often ≤ 0 (with the growth of a number of channels *multicast* in the network).

¹⁷ We take the value of $10^{-9}s$ for Juniper T640. taking an another value does not change the quality of the results.

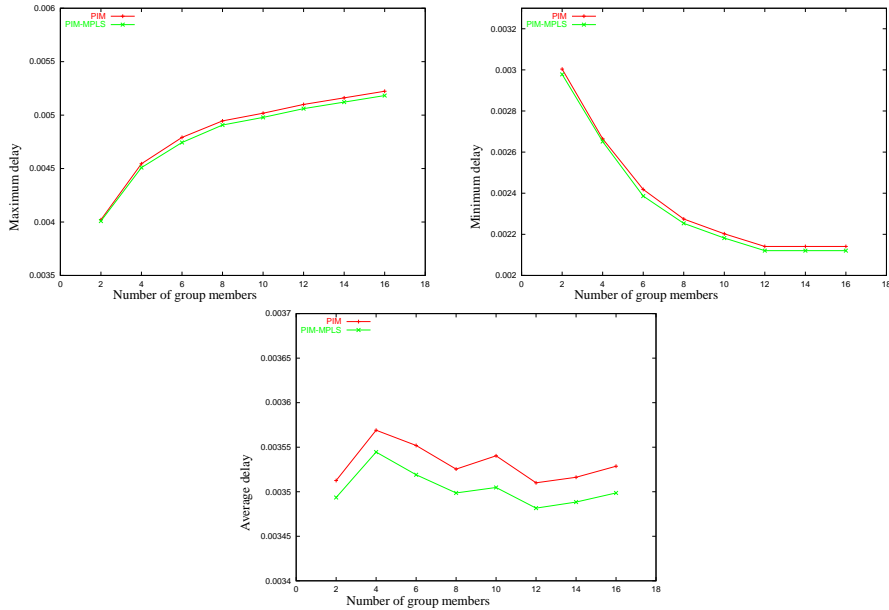


Fig. 7. The global delay (minimum, maximum and average) of a packet for the protocols PIM-SM and PIM-MPLS in the MCI network.

shortest paths tree is identical to the reverse shortest paths tree if it is considered that the network is symmetrical (it is not the case as we already saw in chapter 2 of [8]).

We consider the MCI topology¹⁸ [23] and we use the following scenario : a new node is attached to each CORE node in the MCI network. A specific node is fixed as a source and a variable number of receivers is selected randomly among nodes who are not CORE nodes. For each number of receivers, we carried out 500 simulations by algorithm. Having identified the cost of the tree as being the average cost of the paths from the source towards all the receivers, the figure 8 represents the average cost of the tree built by the protocols MMT¹⁹ and PIM-MPLS for the MCI network. We notice that the tree cost is lower with protocol MMT than with PIM-MPLS protocol, which uses the reverse shortest paths tree.

5 Conclusion

In this paper, we proposed the MMT protocol, which uses MPLS LSP between the branching node routers of a multicast tree in order to reduce routing states in intermediate routers and to increase scalability. Our approach is efficient compared to other multicast protocols and multicast MPLS proposals (PIM-MPLS, *Aggregated multicast*). Indeed, on one hand we use the best paths tree (which

¹⁸ To the link $\langle n1, n2 \rangle$ which connects the nodes $n1$ and $n2$ are associated two costs, $n1-n2$ and $n2-n1$ randomly chosen in the interval $[1, 10]$.

¹⁹ The protocols MMT2 and *Aggregated multicast* offer identical results to protocol MMT.

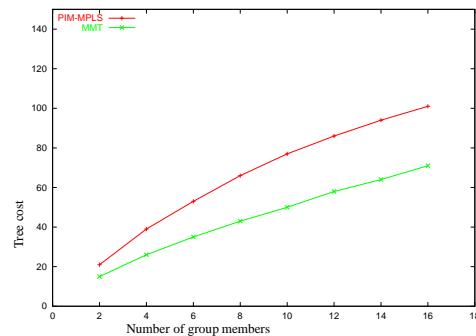


Fig. 8. The cost of the trees constructed with MMT and MMT2 for the MCI network.

coincides with the shortest paths tree in absence of any traffic engineering constraints) to forward packets and on the other hand we use the fast label switching technique of MPLS in the routers. We presented the MMT2 protocol : an extension of the MMT protocol which solve the problem of the mixed routing of the "Network" layer and the "Data Link" layer in CORE routers. We evaluated MMT and MMT2 in term of scalability and efficiency. We noticed a reduction in size of the multicast routing tables compared to the other multicast MPLS approaches. We also noticed a faster packet processing time due to the use of the label switching technique of MPLS in routers. We validated the weak cost carried out by MMT compared to protocols using the reverse shortest paths tree. We conclude finally that the MMT protocol seems promising and adapted to a possible implementation of the multicast traffic engineering in the Internet.

References

1. Rosen, E., Viswanathan, A., Callon, R.: Multiprotocol label switching architecture. IETF RFC 3031 (2001)
2. Awduche, D., Malcom, J., Agogbua, J., O'Dell, M.: Requirements for Traffic Engineering over MPLS. IETF RFC 2702 (1999)
3. Awduche, D., Berger, L., Gan, D., Li, T., Srinivasan, V., Swallow, G.: RSVP-TE: Extensions to RSVP for LSP tunnels. IETF RFC 3209 (2001)
4. Andersson, L., Doolan, P., Feldman, N., Fredette, A., Thomas, B.: LDP Specification. IETF RFC 3036 (2001)
5. Ooms, D., Sales, B., Livens, W., Acharya, A., Griffoul, F., Ansari, F.: Overview of IP Multicast in a Multi-Protocol Label Switching MPLS Environment. IETF RFC 3353 (2002)
6. Ooms, D., Livens, W.: IP Multicast in MPLS Networks. Technical leaflet, Alcatel Corporate Research Center (1999)
7. Boudani, A., Cousin, B., Bonnin, J.M.: MPLS Multicast Traffic Engineering. In: IEEE ROC&C. (2003)
8. Boudani, A.: Routage multicast : gestion des petits groupes et ingnierie de trafic. PhD thesis, Universit de Rennes I (2004)
9. Farinacci, D., Rekhter, Y., Rosen, E.: Using PIM to distribute MPLS labels for multicast routes. IETF Internet draft (2000)

10. Fei, A., Cui, J., Gerla, M., Faloutsos, M.: Aggregated Multicast: An Approach to Reduce Multicast State. In: Proceedings of the Third International COST264 Workshop (NGC 2001) UCL. London. Number 2233 in LNCS (2001) 172–188
11. Estrin, D., Farinacci, D., Helmy, A., Thaler, D., Deering, S., Handley, M., Jacobson, V., Liu, C., Sharma, P., Wei, L.: Protocol Independent Multicast-Sparse Mode (PIM-SM): Protocol Specification. IETF RFC 2362 (1998)
12. Boudani, A., Cousin, B.: A New Approach to Construct Multicast Trees in MPLS Networks. In: The Seventh IEEE Symposium on Computers and Communications. (2002)
13. Cain, B., Deering, S., Thyagarajan, A.: Internet Group Management Protocol, version 3. IETF RFC 3376 (2002)
14. Yang, B., Mohapatra, P.: Edge Router Multicasting With MPLS Traffic Engineering. In: IEEE International Conference on Networks (ICON'02). (2002)
15. Rosen, E., Cai, Y., Tappan, D., Rekhter, Y., Farinacci, D.: Multicast in MPLS/BGP VPNs. IETF Internet draft (2003)
16. Boudani, A., Jawhar, C., Cousin, B., Doughan, M.: A Simulator for Multicast Routing over an MPLS Network. Technical report 1493, IRISA (2002)
17. Fall, K., Varadhan, K.: The NS Manual. UC Berkeley, LBL, USC/ISI, and Xerox PARC (2001)
18. Cui, J., Kim, J., Maggiorini, D., Boussetta, K., Gerla, M.: Aggregated Multicast: A Comparative Study. Special Issue of Cluster Computing: The Journal of Networks, Software and Applications (2003)
19. Cui, J., Kim, J., Maggiorini, D., Boussetta, K., Gerla, M.: Aggregated Multicast: A Comparative Study. In: Networking 2002. (2002)
20. Juniper Networks T640 Performance Test Report. Technical Report TR0112 (2003)
21. Waldvogel, M., Varghese, G., Turner, J., Plattner, B.: Scalable high-speed prefix matching. ACM Transactions on Computer Systems **19** (2001) 440–482
22. Enabling Technologies MPLS. (www.juniper.net/solutions)
23. Apostolopoulos, G., Guerin, R., Kamat, S., Tripathi, S.: Quality of Service Based Routing : A Performance Perspective. In: ACM SIGCOMM. (1998) 913–919