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## Use of Label Switching With ATM

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### Abstract

The MPLS Architecture [1] discusses a way in which ATM switches may be used as Label Switching Routers. The ATM switches run network layer routing algorithms (such as OSPF, IS-IS, etc.), and their data forwarding is based on the results of these routing algorithms. No ATM-specific routing or addressing is needed. ATM switches used in this way are known as ATM-LSRs.

This document extends and clarifies the relevant portions of [1] and [2] by specifying in more detail the procedures which to be used when distributing labels to or from ATM-LSRs, when those labels represent Forwarding Equivalence Classes (FECs, see [1]) for which the routes are determined on a hop-by-hop basis by network layer routing algorithms.

This document also specifies the MPLS encapsulation to be used when sending labeled packets to or from ATM-LSRs, and in that respect is a companion document to [3].

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## [1. Introduction](#)

The MPLS Architecture [1] discusses the way in which ATM switches may be used as Label Switching Routers. The ATM switches run network layer routing algorithms (such as OSPF, IS-IS, etc.), and their data forwarding is based on the results of these routing algorithms. No ATM-specific routing or addressing is needed. ATM switches used in this way are known as ATM-LSRs.



This document extends and clarifies the relevant portions of [1] and [2] by specifying in more detail the procedures which are to be used for distributing labels to or from ATM-LSRs, when those labels represent Forwarding Equivalence Classes (FECs, see [1]) for which the routes are determined on a hop-by-hop basis by network layer routing algorithms. The label distribution technique described here is referred to in [1] as "downstream-on-demand". This label distribution technique is mandatory for ATM-LSRs that are not capable of "VC merge" (defined in [section 2](#)), and is optional for ATM-LSRs that are capable of VC merge.

Label distribution techniques used when the routes are explicitly chosen, or when the FECs consist of multicast packets, are not considered in this document, and further statements made in this document about ATM-LSR label distribution do not necessarily apply in those cases.

The label distribution procedures specified herein are required for use when the ATM-LSRs are not capable of "VC merge", and may also be used if the ATM-LSRs are capable of VC merge. Label distribution procedures for the case of "VP merge" are not considered in this document.

This document also specifies the MPLS encapsulation to be used when sending labeled packets to or from ATM-LSRs, and in that respect is a companion document to [3]. The specified encapsulation is to be used for multicast or explicitly routed labeled packets as well.

This document uses terminology from [1].

## **2. Definitions**

A Label Switching Router (LSR) is a device which implements the label switching control and forwarding components described in [1].

A label switching controlled ATM (LC-ATM) interface is an ATM interface controlled by the label switching control component. When a packet traversing such an interface is received, it is treated as a labeled packet. The packet's top label is inferred either from the contents of the VPI field, the contents of the VCI field, or the combined contents of the VPI and VCI fields. Any two LDP peers which are connected via an LC-ATM interface will use LDP negotiations to determine which of these three cases is applicable to that interface.

An ATM-LSR is a LSR with a number of LC-ATM interfaces which forwards cells between these interfaces using labels carried in the VCI and/or VPI field.



A frame-based LSR is a LSR which forwards complete frames between its interfaces. Note that such a LSR may have zero, one or more LC-ATM interfaces.

In general, an LC-ATM interface will be used either to connect two ATM-LSRs, or to connect an ATM-LSR to a frame-based LSR.

An ATM-LSR domain is a set of ATM-LSRs which are mutually interconnected by LC-ATM interfaces.

The Edge Set of an ATM-LSR domain is the set of frame-based LSRs which are connected to members of the domain by LC-ATM interfaces. A frame-based LSR which is a member of an Edge Set of an ATM-LSR domain may be called an Edge LSR.

VC-merge is the process by which a switch receives cells on several incoming VCIs and transmits them on a single outgoing VCI without causing the cells of different AAL5 PDUs to become interleaved.

### **3. Special Characteristics of ATM Switches**

While the MPLS architecture permits considerable flexibility in LSR implementation, an ATM-LSR is constrained by the capabilities of the (possibly pre-existing) hardware and the restrictions on such matters as cell format imposed by ATM standards. Because of these constraints, some special procedures are required for ATM-LSRs.

Some of the key features of ATM switches that affect their behavior as LSRs are:

- the label swapping function is performed on fields (the VCI and/or VPI) in the cell header; this dictates the size and placement of the label(s) in a packet.
- multipoint-to-point and multipoint-to-multipoint VCs are generally not supported. This means that most switches cannot support 'VC-merge' as defined above.
- there is generally no capability to perform a 'TTL-decrement' function as is performed on IP headers in routers.

This document describes ways of applying label switching to ATM switches which work within these constraints.



#### **4. Label Switching Control Component for ATM**

To support label switching an ATM switch must implement the control component of label switching. This consists primarily of label allocation, distribution, and maintenance procedures. Label binding information is communicated by several mechanisms, notably the Label Distribution Protocol (LDP) [2]. This document imposes certain requirements on the LDP.

This document considers only the case where the label switching control component uses information learned directly from network layer routing protocols. It is presupposed that the switch participates as a peer in these protocols (e.g., OSPF, IS-IS).

In some cases, LSRs make use of other protocols (e.g. RSVP, PIM, BGP) to distribute label bindings. In these cases, an ATM-LSR would need to participate in these protocols. However, these are not explicitly considered in this document.

Support of label switching on an ATM switch does not require the switch to support the ATM control component defined by the ITU and ATM Forum (e.g., UNI, PNNI). An ATM-LSR may optionally respond to OAM cells.

#### **5. Hybrid Switches (Ships in the Night)**

The existence of the label switching control component on an ATM switch does not preclude the ability to support the ATM control component defined by the ITU and ATM Forum on the same switch and the same interfaces. The two control components, label switching and the ITU/ATM Forum defined, would operate independently.

Definition of how such a device operates is beyond the scope of this document. However, only a small amount of information needs to be consistent between the two control components, such as the portions of the VPI/VCI space which are available to each component.





## **6. Use of VPI/VCIs**

Label switching is accomplished by associating labels with Forwarding Equivalence Classes, and using the label value to forward packets, including determining the value of any replacement label. See [1] for further details. In an ATM-LSR, the label is carried in the VPI and/or VCI field. Just as in conventional ATM, for a cell arriving at an interface, the VPI/VCI is looked up, replaced, and the cell is switched.

In addition, if two LDP peers are connected via an LC-ATM interface, a non-MPLS connection, capable of carrying unlabelled IP packets, must always be available. This non-MPLS connection is used to carry LDP packets between the two peers, and may also be used (but is not required to be used) for any other unlabeled packets (such as OSPF packets, etc.). The LLC/SNAP encapsulation of [RFC 1483](#) is always used on the non-MPLS connection.

LDP may be used to advertise additional VPI/VCIs to carry control information or non-labelled packets. These may use either the null encapsulation, as defined in [Section 5.1 of RFC1483](#), or the LLC/SNAP encapsulation, as defined in [Section 4.1 of RFC1483](#).

### **6.1. Direct Connections**

We say that two LSRs are "directly connected" over an LC-ATM interface if all cells transmitted out that interface by one LSR will reach the other, and there are no ATM switches between the two LSRs.

When two LSRs are directly connected via an LC-ATM interface, they jointly control the allocation of VPIs/VCIs on the interface connecting them. They may agree to use the entire VPI/VCI field to encode a single label. Alternatively, they may agree to use the VPI field to encode the top label in the stack, and the VCI field to encode the second label in the stack. However, the latter alternative is only allowed when the top label represents a FEC for which the Label Switched Path (LSP, see [1]) consists entirely of LSRs, directly connected via LC-ATM interfaces, which have agreed to encode the top label in the VPI field and the second label in the VCI field.

The default VPI/VCI value for the NON-MPLS connection is VPI 0, VCI 32. Other values can be configured, as long as both parties are aware of the configured value.

It is prohibited to encode any label as a VPI/VCI value whose VCI part is in the range 0-32 inclusive.



With the exception of these reserved values, the VPI/VCI values used in the two directions of the link may be treated as independent spaces.

The allowable ranges of VCIs are communicated through LDP.

## **6.2. Connections via an ATM VP**

Sometimes it can be useful to treat two LSRs as adjacent (in some LSP) across an LC-ATM interface, even though the connection between them is made through an ATM "cloud" via an ATM Virtual Path. In this case, the VPI field is not available to MPLS, and the label must be encoded entirely within the VCI field.

In this case, the default VCI value of the non-MPLS connection between the LSRs is 32. The VPI is set to whatever is required to make use of the Virtual Path.

It is prohibited to encode any label as a VPI/VCI value whose VCI part is in the range 0-32 inclusive.

With the exception of these reserved values, the VPI/VCI values used in the two directions of the link may be treated as independent spaces.

The allowable ranges of VPI/VCIs are communicated through LDP. If more than one VPI is used for label switching, the allowable range of VCIs may be different for each VPI, and each range is communicated through LDP.

## **6.3. Connections via an ATM SVC**

Sometimes it may be useful to treat two LSRs as adjacent (in some LSP) across an LC-ATM interface, even though the connection between them is made through an ATM "cloud" via a set of ATM Switched Virtual Circuits. In this case, the procedures described in [4] must be used to assign a VCID to each such VC, and LDP is used to bind a VCID to a FEC. The top label of a received packet is then inferred (via a one-to-one mapping) from the virtual circuit on which the packet arrived.

In this case, there is no default VPI or VCI value for the non-MPLS connection.



## **7. Label Distribution and Maintenance Procedures**

This document discusses the use of "downstream-on-demand" label distribution (see [\[1\]](#)) by ATM-LSRs. These label distribution procedures are mandatory for ATM-LSRs that do not support VC-merge, and may also be used by ATM-LSRs that do support VC-merge. The procedures differ somewhat in the two cases, however. We therefore describe the two scenarios in turn. We begin by describing the behavior of members of the Edge Set of an ATM-LSR domain; these "Edge LSRs" are not themselves ATM-LSRs, and their behavior is the same whether the domain contains VC-merge capable LSRs or not.

### **7.1. Edge LSR Behavior**

Consider a member of the Edge Set of an ATM-LSR domain. Assume that, as a result of its routing calculations, it selects an ATM-LSR as the next hop of a certain FEC, and that the next hop is reachable via a LC-ATM interface. The Edge LSR uses LDP to request a label binding for that FEC from the next hop. The hop count field in the request is set to 1. Once the Edge LSR receives the label binding information, it may use MPLS forwarding procedures to transmit packets in the specified FEC, using the specified label as an outgoing label. (Or using the VPI/VCI that corresponds to the specified VCID as the outgoing label, if VCIDs are being used.)

The binding received by the edge LSR may contain a hop count, which represents the number of hops a packet will take to cross the ATM-LSR domain when using this label. If there is a hop count associated with the binding, the ATM-LSR should adjust the packet's TTL by this amount before transmitting the packet. The procedures for doing so are specified in [section 9](#). The procedures for encapsulating the packets, are specified in [section 8](#).

When a member of the Edge Set of the ATM-LSR domain receives a label binding request from an ATM-LSR, it allocates a label, and returns (via LDP) a binding containing the allocated label back to the peer that originated the request. It sets the hop count in the binding to 1.

When a routing calculation causes an Edge LSR to change the next hop for a particular FEC, and the former next hop was in the ATM-LSR domain, the Edge LSR should notify the former next hop (via LDP) that the label binding associated with the FEC is no longer needed.



## **7.2. Conventional ATM Switches (non-VC-merge)**

When an ATM-LSR receives (via LDP) a label binding request for a certain FEC from a peer connected to the ATM-LSR over a LC-ATM interface, the ATM-LSR takes the following actions:

- it allocates a label,
- it requests (via LDP) a label binding from the next hop for that FEC;
- it returns (via LDP) a binding containing the allocated incoming label back to the peer that originated the request.

The hop count field in the request that the ATM-LSR sends (to the next hop LSR) is set to the hop count field in the request that it received from the upstream LSR plus one. If the resulting hop count exceeds a configured maximum value, the request is not sent to the next hop, and the ATM-LSR notifies the upstream neighbor that its binding request cannot be satisfied.

Otherwise, once the ATM-LSR receives the binding from the next hop, it places the label from the binding into the outgoing label component of the LIB entry.

The ATM-LSR may choose to wait for the request to be satisfied from downstream before returning the binding upstream. This is a form of "ordered control" (as defined in [1] and [2]), in particular "ingress-initiated ordered control". In this case, the ATM-LSR increments the hop count it received from downstream and uses this value in the binding it returns upstream. However, if the hop count exceeds a configured maximum value, a label binding is not passed upstream. Rather, the upstream LDP peer is informed that the requested label binding cannot be satisfied.

Alternatively, the ATM-LSR may return the binding upstream without waiting for a binding from downstream ("independent" control, as defined in [1] and [2]). In this case, it uses a reserved value for hop count in the binding, indicating that the true hop count is unknown. The correct value for hop count will be returned later, as described below.

Note that an ATM-LSR, or a member of the edge set of an ATM-LSR domain, may receive multiple binding requests for the same FEC from the same ATM-LSR. It must generate a new binding for each request (assuming adequate resources to do so), and retain any existing binding(s). For each request received, an ATM-LSR should also generate a new binding request toward the next hop for the FEC.





When a routing calculation causes an ATM-LSR to change the next hop for a FEC, the ATM-LSR should notify the former next hop (via LDP) that the label binding associated with the FEC is no longer needed.

When a LSR receives a notification that a particular label binding is no longer needed, the LSR may deallocate the label associated with the binding, and destroy the binding. In the case where an ATM-LSR receives such notification and destroys the binding, it should notify the next hop for the FEC that the label binding is no longer needed. If a LSR does not destroy the binding, it may re-use the binding only if it receives a request for the same FEC with the same hop count as the request that originally caused the binding to be created.

When a route changes, the label bindings are re-established from the point where the route diverges from the previous route. LSRs upstream of that point are (with one exception, noted below) oblivious to the change.

Whenever a LSR changes its next hop for a particular FEC, if the new next hop is reachable via an LC-ATM interface, then for each label that it has bound to that FEC, and distributed upstream, it must request a new label binding from the new next hop.

When an ATM-LSR receives a label binding for a particular FEC from a downstream neighbor, it may already have provided a corresponding label binding for this FEC to an upstream neighbor, either because it is using independent control, or because the new binding from downstream is the result of a routing change. In this case, it should extract the hop count from the new binding and increment it by one. If the new hop count is different from that which was previously conveyed to the upstream neighbor (including the case where the upstream neighbor was given the value 'unknown') the ATM-LSR must notify the upstream neighbor of the change. Each ATM-LSR in turn increments the hop count and passes it upstream until it reaches the ingress Edge LSR. If at any point the value of the hop count equals a configured maximum hop count value, the ATM-LSR should withdraw the binding from the upstream neighbor.

Whenever an ATM-LSR originates a label binding request to its next hop LSR as a result of receiving a label binding request from another (upstream) LSR, and the request to the next hop LSR is not satisfied, the ATM-LSR should destroy the binding created in response to the received request, and notify the requester (via LDP).

If an ATM-LSR receives a binding request containing a hop count that exceeds a configurable maximum, no binding should be established and an error message should be returned to the requester.



When a LSR determines that it has lost its LDP session with another LSR, the following actions are taken. Any binding information learned via this connection must be discarded. For any label bindings that were created as a result of receiving label binding requests from the peer, the LSR may destroy these bindings (and deallocate labels associated with these binding).

An ATM-LSR should use 'split-horizon' when it satisfies binding requests from its neighbors. That is, if it receives a request for a binding to a particular FEC and the LSR making that request is, according to this ATM-LSR, the next hop for that FEC, it should not return a binding for that route.

Note that if ordered control is used, it is not possible to create looping paths consisting entirely of non-VC-merging ATM-LSRs. LDP messages might be sent in a loop until the hop count reaches the configured maximum, but data would not loop.

Note that non-merging ATM-LSRs must use "conservative label retention mode" [1].

### **7.3. VC-merge-capable ATM Switches**

Relatively minor changes are needed to accommodate ATM-LSRs which support VC-merge. The primary difference is that a VC-merge-capable ATM-LSR needs only one outgoing label per FEC, even if multiple requests for label bindings to that FEC are received from upstream neighbors.

When a VC-merge-capable ATM-LSR receives a binding request from an upstream LSR for a certain FEC, and it does not already have an outgoing label binding for that FEC (or an outstanding request for such a label binding), it issues a bind request to its next hop just as it would do if it were not merge-capable. If, however, it already has an outgoing label binding for that FEC, it does not need to issue a downstream binding request. Instead, it allocates an incoming label, and returns that label in a binding to the upstream requester. When packets with that label as top label are received from the requester, the top label value will be replaced with the existing outgoing label value that corresponds to the same FEC.

If the ATM-LSR does not have an outgoing label binding for the FEC, but does have an outstanding request for one, it does not issue another request.

When sending a label binding upstream, the hop count associated with the corresponding binding from downstream is incremented by 1, and



the result transmitted upstream as the hop count associated with the new binding.

Note that, just like conventional ATM-LSRs and members of the edge set of the ATM-LSR domain, a VC-merge-capable ATM-LSR must issue a new binding every time it receives a request from upstream, since there may be switches upstream which do not support VC-merge. However, it only needs to issue a corresponding binding request downstream if it does not already have a label binding for the appropriate route.

When a change in the routing table of a VC-merge-capable ATM-LSR causes it to select a new next hop for one of its FECs, it may optionally release the binding for that route from the former next hop. If it doesn't already have a corresponding binding for the new next hop, it must request one. (The choice between conservative and liberal label retention mode is an implementation option.)

If a new binding is obtained, which contains a hop count that differs from that which was received in the old binding, then the ATM-LSR must take the new hop count, increment it by one, and notify any upstream neighbors who have label bindings for this FEC of the new value. Just as with conventional ATM-LSRs, this enables the new hop count to propagate back towards the ingress of the ATM-LSR domain. If at any point the hop count exceeds the configurable maximum value, then the label bindings for this route must be withdrawn from all upstream neighbors to whom a binding was previously provided. This ensures that any loops caused by routing transients will be detected and broken.

Complete prevention of transient looping paths can be achieved by means of the techniques described in [5], which work with any mix of merging and non-merging ATM-LSRs. Note that the loop prevention technique described in [1] and [2] cannot be used along with downstream-on-demand label distribution.

## **8. Encapsulation**

The procedures described in this section affect only the Edge LSRs of the ATM-LSR domain. The ATM-LSRs themselves do not modify the encapsulation in any way.

In general, when a labeled packet is transmitted on an LC-ATM interface, where the VPI/VCI (or VCID) is interpreted as the top one or two labels in the label stack, it is also necessary for the packet to be encapsulated as specified in [3], and for the resulting packet to be placed directly into the AAL5 frame.



Let  $n$  be the depth of a packet's label stack, and let  $c$  be the number of labels (1 or 2) which are represented by the VPI/VCI or VCID.

If  $n == c$ , the packet should be encapsulated as specified in [3], with at least one, but no more than  $n$ , label stack entries. The label value of the bottom label stack entry should be set to the distinguished "Explicit NULL" value for the network layer protocol of the packet. The label value of any other label in the stack should be set to the "IPv4 Explicit NULL" value as defined in [3].

Essentially, this creates at least four bytes of overhead whose meaning is " $n == c$ ". The only ways to eliminate this overhead are:

- through apriori knowledge that  $n == c$ ;
- by using two VCs per FEC, one for those packets where  $n == c$ , and one for those packets where  $n > c$ .

While either of these techniques is permitted, it is doubtful that they have any practical utility.

If  $n > c$ , the packet should be encapsulated as specified in [3]. The number of label stack entries contained in that encapsulation,  $e$ , must be between  $n$  and  $n - c$  inclusive. If more than  $n - c$  label stack entries are encoded, the top  $e - n$  labels must have their label values set to the distinguished value "IPv4 Explicit NULL", as defined in [3].

Note that if  $n > c$  for some packet, it is an implementation choice as to whether the generic encapsulation should contain  $n$  or  $n - c$  entries. Using the smaller number of entries in the encapsulation saves communications bandwidth, but may complicate the logic of the transmit and/or received forwarding paths of the Edge LSRs.

In any case, the packet's outgoing TTL, and its CoS, are carried in the TTL and CoS fields respectively of the top stack entry in the generic encapsulation. If the generic encapsulation is not present, the outgoing TTL is carried in the TTL field of the network layer header.





## **9. TTL Manipulation**

The procedures described in this section affect only the Edge LSRs of the ATM-LSR domain. The ATM-LSRs themselves do not modify the TTL in any way.

The details of the TTL adjustment procedure are as follows. If a packet was received by the Edge LSR as an unlabeled packet, the "incoming TTL" comes from the IP header. (Procedures for other network layer protocols are for further study.) If a packet was received by the Edge LSR as a labeled packet, using the encapsulation specified in [3], the "incoming TTL" comes from the entry at the top of the label stack.

If a hop count has been associated with the label binding that is used when the packet is forwarded, the "outgoing TTL" is set to the larger of (a) 0 or (b) the difference between the incoming TTL and the hop count. If a hop count has not been associated with the label binding that is used when the packet is forwarded, the "outgoing TTL" is set to the larger of (a) 0 or (b) one less than the incoming TTL.

If this causes the outgoing TTL to become zero, the packet must not be transmitted as a labeled packet using the specified label. The packet can be treated in one of two ways:

- it may be treated as having expired; this may cause an ICMP message to be transmitted;
- the packet may be forwarded, as an unlabeled packet, with a TTL that is 1 less than the incoming TTL; such forwarding would need to be done over a non-MPLS connection.

Of course, if the incoming TTL is 1, only the first of these two options is applicable.

If the packet is forwarded as a labeled packet, the outgoing TTL is carried as specified in [section 8](#).

When an Edge LSR receives a labeled packet over an LC-ATM interface, it obtains the incoming TTL from the top label stack entry of the generic encapsulation, or, if that encapsulation is not present, from the IP header.

If the packet's next hop is an ATM-LSR, the outgoing TTL is formed using the procedures described in this section. Otherwise the outgoing TTL is formed using the procedures described in [3].

The procedures in this section are intended to apply only to unicast



packets.

## **10. Security Considerations**

Security considerations are not addressed in this document.

## **11. Intellectual Property Considerations**

Cisco Systems may seek patent or other intellectual property protection for some or all of the technologies disclosed in this document. If any standards arising from this document are or become protected by one or more patents assigned to Cisco Systems, Cisco intends to disclose those patents and license them under openly specified and non-discriminatory terms, for no fee.

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## **13. Acknowledgments**

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