Fundamentals
Multiprotocol Label Switching – MPLS II

Design of Telecommunication Infrastructures
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Goals of the section

- ☑ The need for LDP
- ☑ The operation of LDP

Label Distribution Protocol

- LDP Operation
- Targeted LDP Session & Authentication
- Controlling Advertisement
- MPLS LDP-IGP Synchronization
- MPLS LDP Session Protection

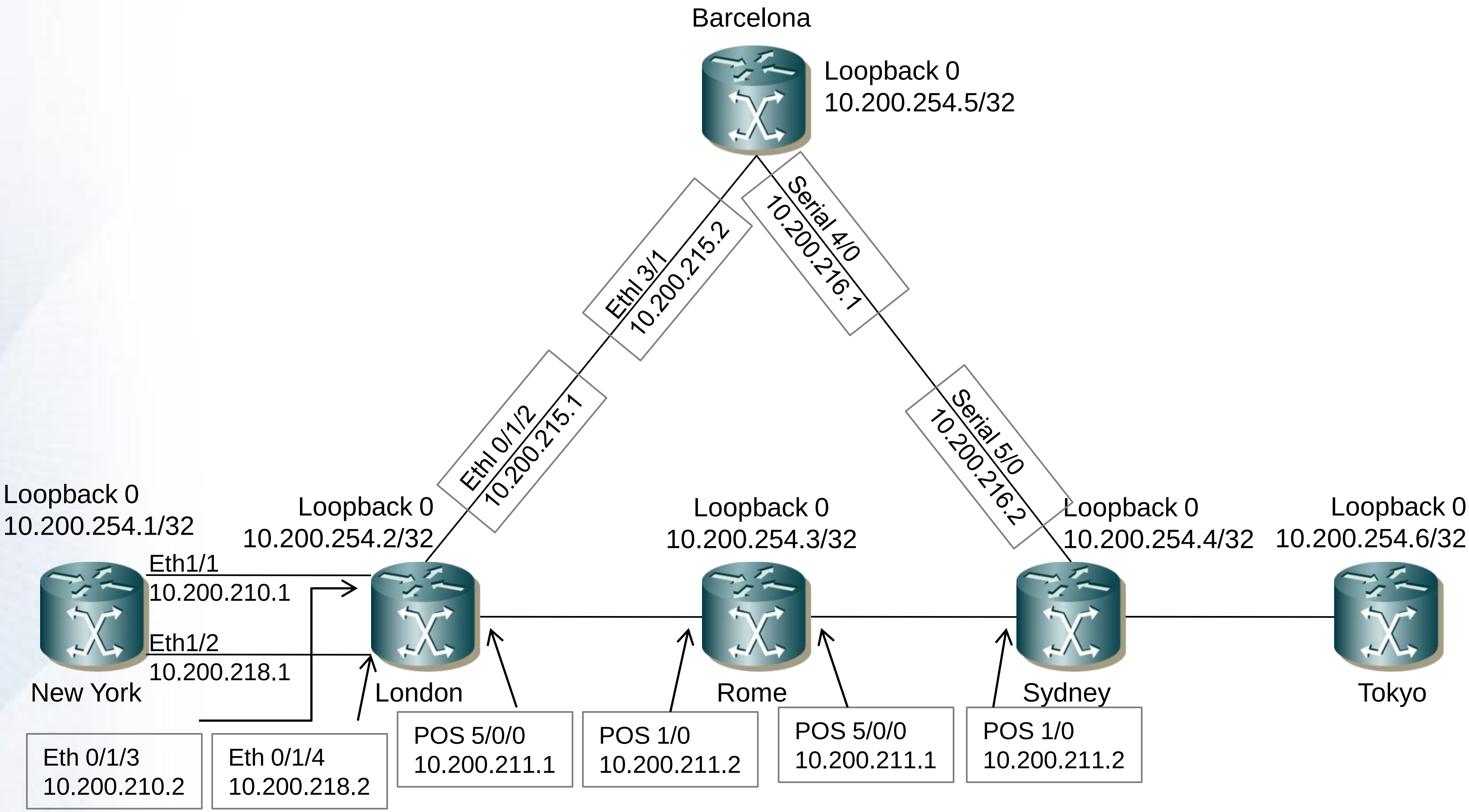
- Review Questions

Why LDP?

Review

- MPLS uses labels to forward packets by the LSRs
- Labels need to be redistributed
  - Piggyback labels on existing IGPs or
  - Label distribution protocol (RFC 3036)
- BGP carries external routes
  - More efficient if it carries Labels too
  - It is multiprotocol (MP-BGP, RFC 2283)

Our Network


Barcelona
Loopback 0
10.200.254.5/32
Ethl 3/1
10.200.215.2
Serial 4/0
10.200.216.1
Ethl 0/1/2
10.200.215.1
Serial 5/0
10.200.216.2
Loopback 0
10.200.254.1/32
Loopback 0
10.200.254.2/32
Loopback 0
10.200.254.3/32
Loopback 0
10.200.254.4/32
Loopback 0
10.200.254.6/32
Eth1/1
10.200.210.1
Eth1/2
10.200.218.1
New York
London
Rome
Sydney
Tokyo
Eth 0/1/3
10.200.210.2
Eth 0/1/4
10.200.218.2
POS 5/0/0
10.200.211.1
POS 1/0
10.200.211.2
POS 5/0/0
10.200.211.1
POS 1/0
10.200.211.2

LDP Overview

- MPLS overview
  1. All LSRs must run LDP and exchange label bindings
  2. All LSR have labels for the FECs
  3. Packets are forwarded on the LSP
  4. LSR perform *pop/push/swap* operations looking into the LFIB
- LIB fed by label bindings
  - LDP for IGP; RSVP for MPLS-TE; MP-BGP for BGP
- LDP functions
  1. The discovery of LSRs that are running LDP
  2. Session establishment and maintenance
  3. Advertising of label mappings
  4. Housekeeping by means of notification

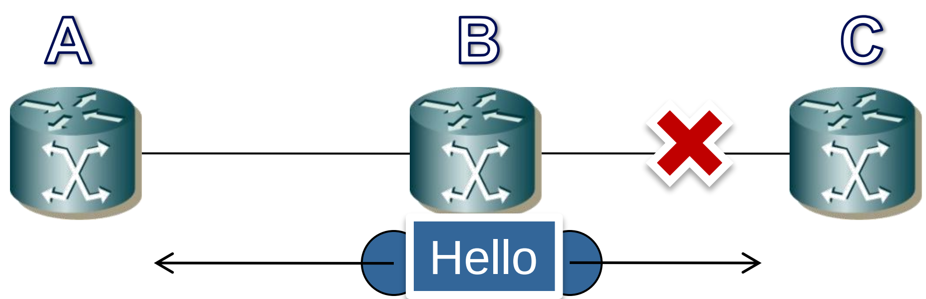
LDP operation

The discovery of LSRs

- LSRs send *Hello* messages on all LDP enabled links
  - *"Hello"* are multicast UDP packets sent every "*Hello interval*" to "all routers in this subnet" (224.0.0.2) using port 646
  - Hello message contains a *Hold time*

neighbor	Hold
A	5000ms
~~C~~	~~5000ms~~

neighbor	Hold
B	5000ms



neighbor	Hold
~~B~~	~~5000ms~~

Example of LSR neighbors

The discovery of LSRs

london# show mpls ldp discovery detail

Local LDP Identifier:

4 bytes + 2 bytes: **10.200.254.2:0** → *Platform wide label space*

Discovery Sources:

Interfaces:

From Barcelona:

Ethernet0/1/2 (ldp): xmit/recv
Enabled: Interface config
Hello interval: 5000 ms; Transport IP addr: 10.200.254.2
LDP Id: 10.200.254.5:0
Src IP addr: 10.200.215.2; Transport IP addr: 10.200.254.5
Hold time: 15 sec; Proposed local/peer: 15/15 sec
Reachable via 10.200.254.5/32

From New York:

Ethernet0/1/3 (ldp): xmit/recv
Enabled: Interface config
Hello interval: 5000 ms; Transport IP addr: 10.200.254.2
LDP Id: 10.200.254.1:0
Src IP addr: 10.200.210.1; Transport IP addr: 10.200.254.1
Hold time: 15 sec; Proposed local/peer: 15/15 sec
Reachable via 10.200.254.1/32

(continue …)

Establishment of LDP Session

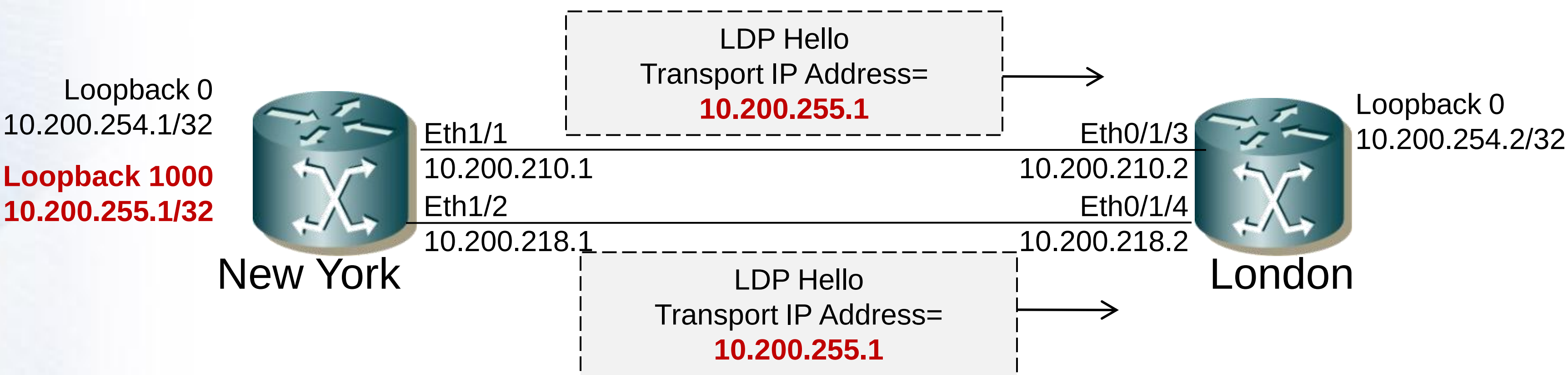
Session Establishment

- After discovery → session establishment
- Parameters negotiated over TCP connection
  - Timer values
  - Label Distribution method
  - VPI/VCI (for label controlled ATM, LC-ATM)
  - DLCI (for LC-Frame Relay)
- Session Maintenance
  - Exchange of LDP packets or Keepalives

Example of LDP Session

Session Establishment

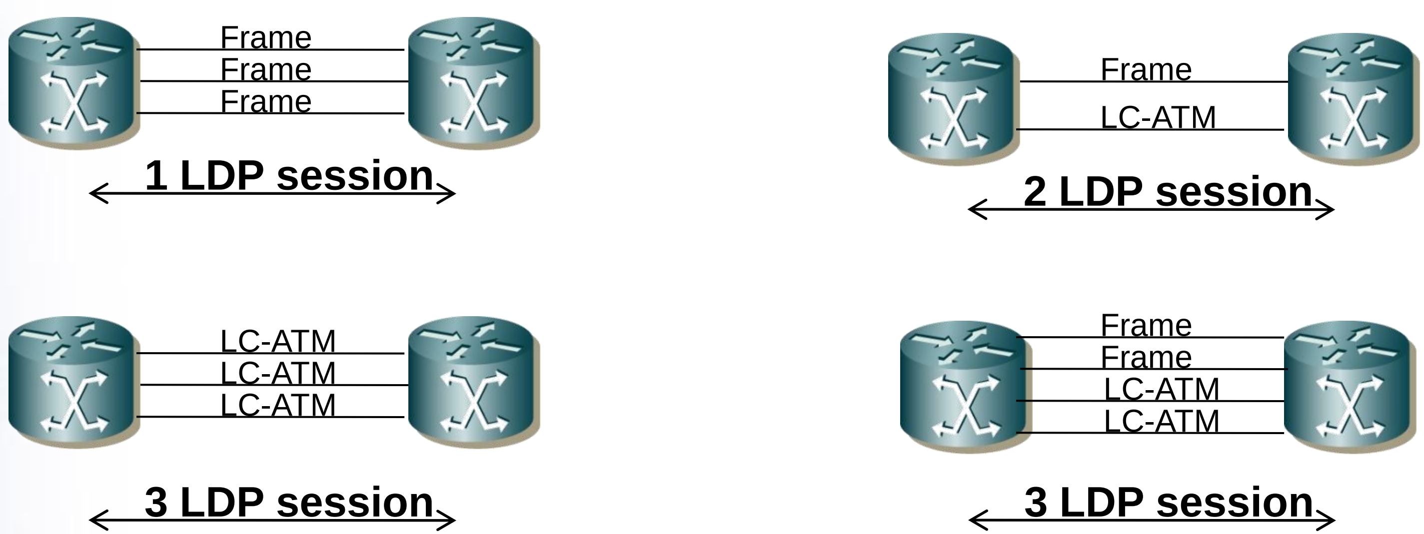
```
london#show mpls ldp neighbor 10.200.254.5 detail
    Peer LDP Ident: 10.200.254.5:0; Local LDP Ident 10.200.254.2:0
        TCP connection: 10.200.254.5.11537 - 10.200.254.2.646
        State: Oper; Msgs sent/rcvd: 16/19; Downstream; Last TIB rev sent 50
        Up time: 00:00:36; UID: 9; Peer Id 1;
        LDP discovery sources:
            Ethernet0/1/2; Src IP addr: 10.200.215.2
                holdtime: 15000 ms, hello interval: 5000 ms
        Addresses bound to peer LDP Ident:
            10.200.254.5 10.200.215.2 10.200.216.1
        Peer holdtime: 180000 ms; KA interval: 60000 ms; Peer state: estab
```



Several LDP Sessions?

Session Establishment

- Per-platform (frame-mode) → 1 session
- Per Interface (LC-ATM mode) → n sessions



Advertisement modes

Advertisement of Label mappings

- Advertising label mappings or label bindings is the main purpose of LDP
  - Unsolicited Downstream (UD) versus Downstream-on-Demand (DoD) advertisement mode
  - Liberal Label Retention (LLR) versus Conservative Label Retention (CLR) mode
  - Independent LSP Control versus Ordered LSP Control mode

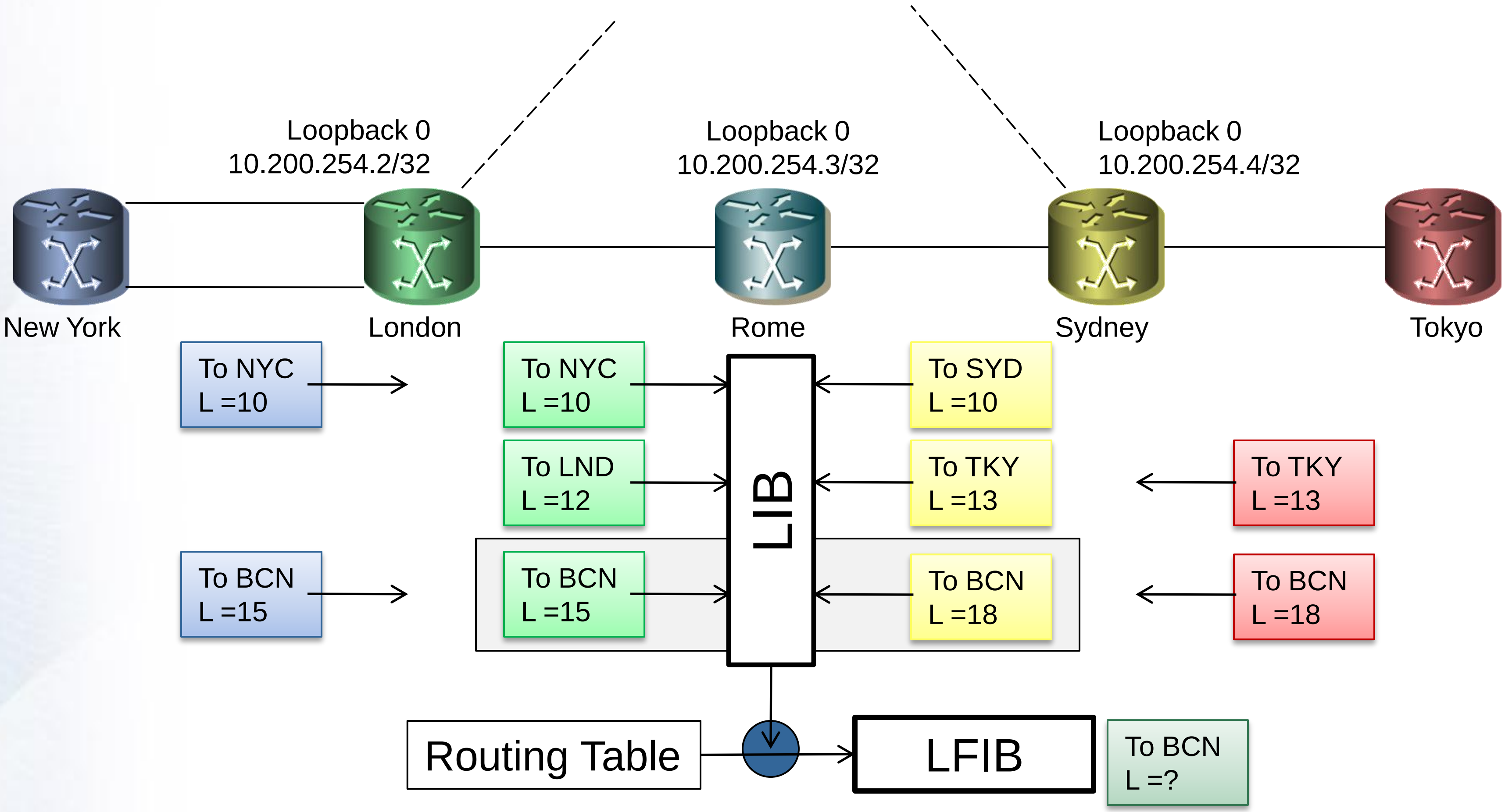
Advertisement of mappings

Advertisement of Label mappings

- **In UD Mode**
  - Peers distribute label bindings unsolicited
  - Set of label bindings (LDP ID, Label) per prefix
  - Several routers: multiple label bindings for each prefix
  - All label bindings received → LIB
  - IGP → routing table → choose one label binding per prefix
  - Populate LFIB with final label bindings for each prefix

Advertisement of mappings

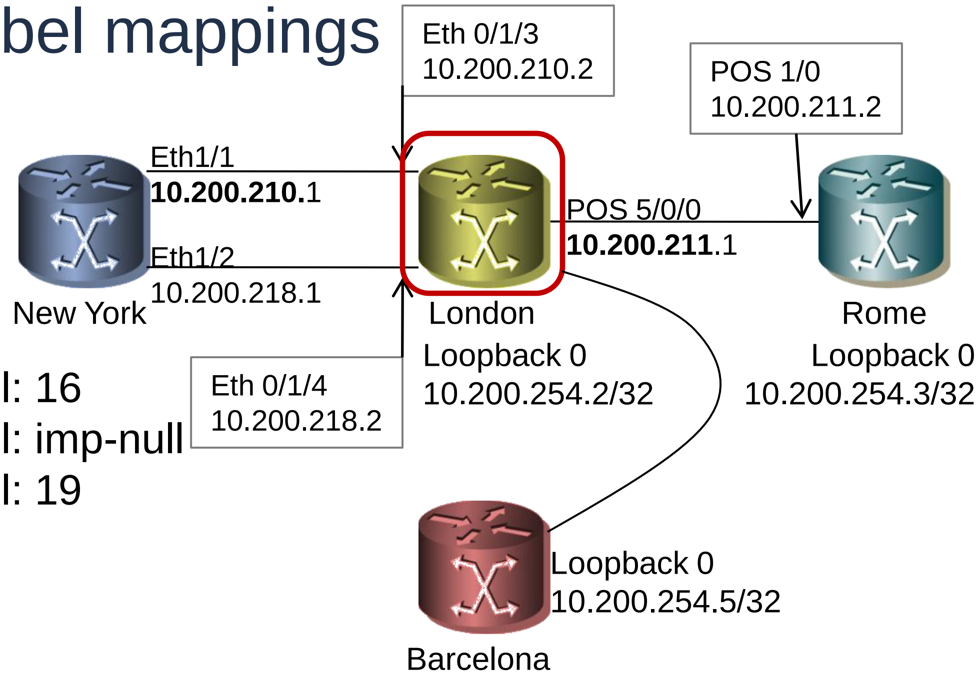
Advertisement of Label mappings



LABEL DISTRIBUTION PROTOCOL – LDP Operation

Example of a LIB

Advertisement of Label mappings



london#show mpls ldp bindings

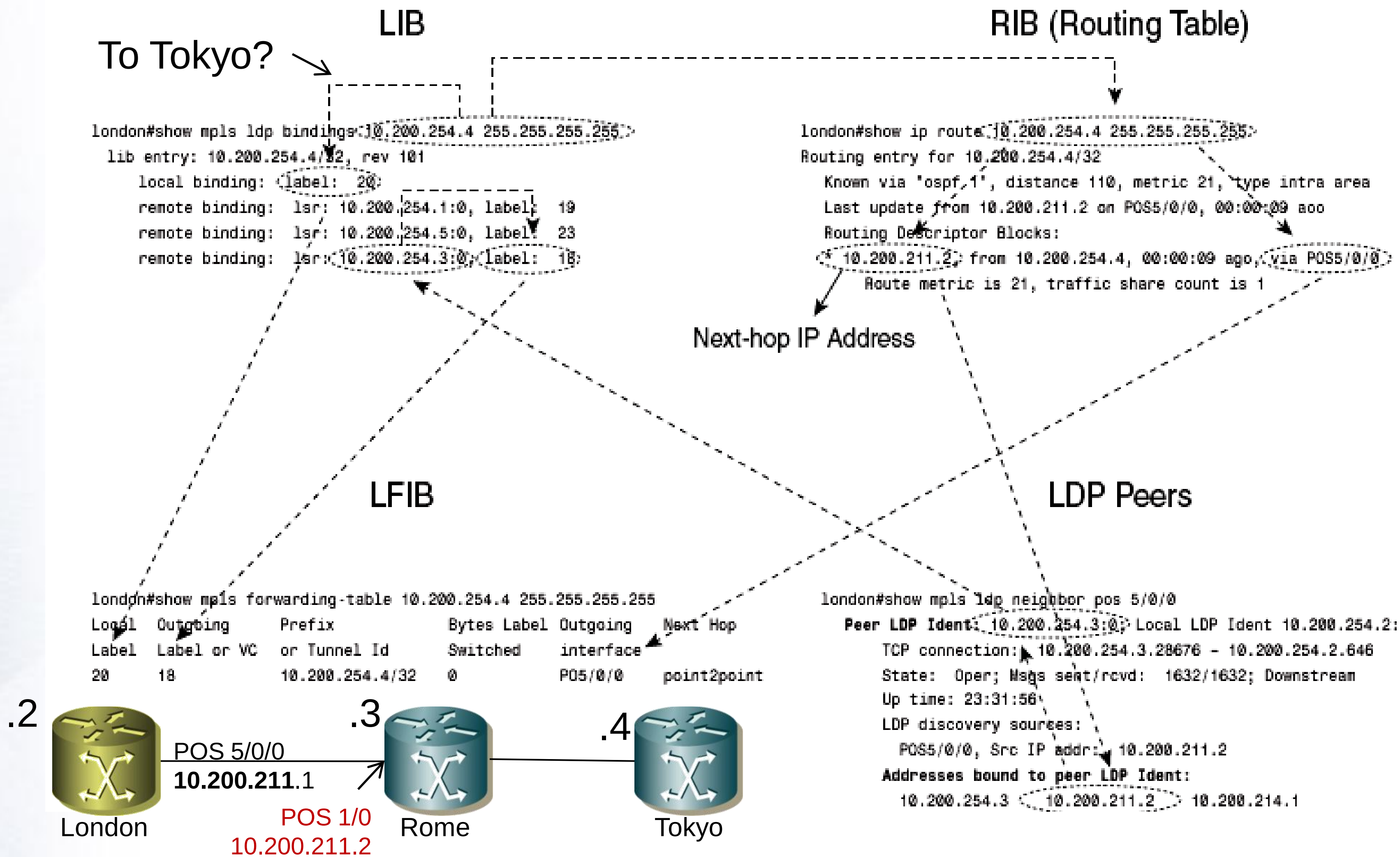
lib entry: **10.200.210.0**/24, rev 4
local binding: label: imp-null
remote binding: lsr: 10.200.254.5:0, label: 16
remote binding: lsr: 10.200.254.1:0, label: imp-null
remote binding: lsr: 10.200.254.3:0, label: 19

lib entry: **10.200.211.0**/24, rev 12
local binding: label: imp-null
remote binding: lsr: 10.200.254.5:0, label: 18
remote binding: lsr: 10.200.254.1:0, label: 32
remote binding: lsr: 10.200.254.3:0, label: imp-null

lib entry: **10.200.254.1**/32, rev 31
local binding: label: 24 → In label
remote binding: lsr: 10.200.254.5:0, label: 22
remote binding: lsr: 10.200.254.1:0, label: imp-null → Out label
remote binding: lsr: 10.200.254.3:0, label: 26

Example of a LFIB

Advertisement of Label mappings



Label Withdrawing

Advertisement of Label mappings

- LDP peers keep label bindings until,
  - LDP session goes down
  - the label is withdrawn
- Implicit null Label → non-reserved Label
  - Directly connected prefix goes down
- Label withdraw message to LDP peers

Housekeeping

Housekeeping by means of notification

- Notification messages for signaling events
  - Malformed protocol data unit (PDU) or message
  - Unknown or malformed type-length-value (TLV)
  - Session keepalive timer expiration
  - Unilateral session shutdown
  - Initialization message events
  - Events resulting from other messages
  - Internal errors
  - Loop detection
  - Miscellaneous events

Targeted LDP sessions

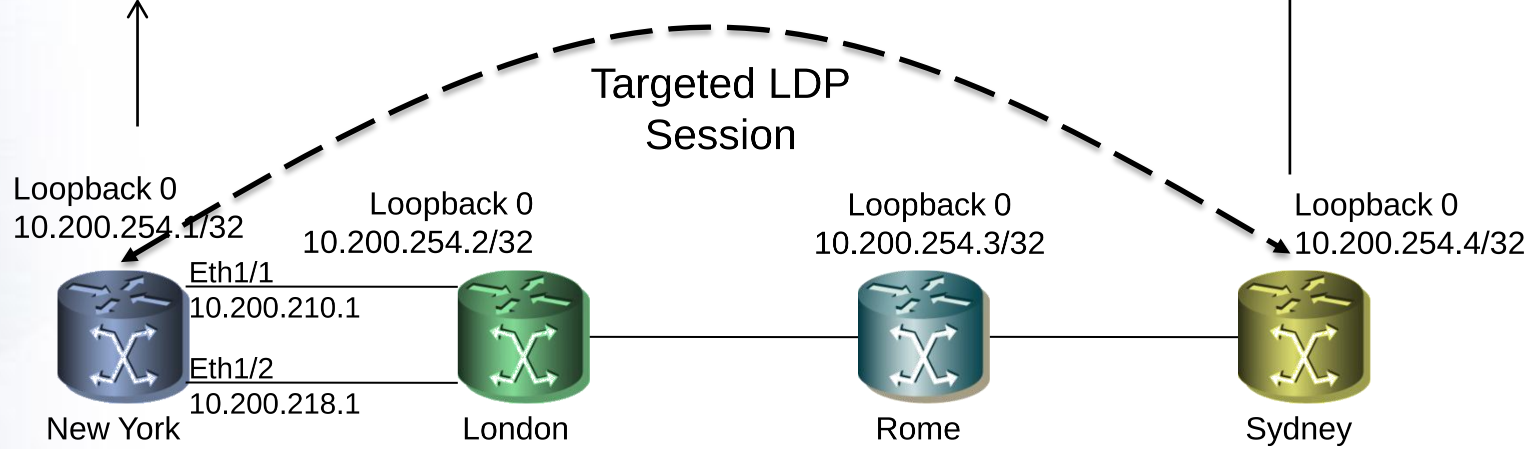
- Need for LDP sessions between remote peers
  - AToM (Any Transport over MPLS)
  - MPLS-TE tunnels in MPLS VPNs
- Advantages
  - Improve the label convergence time in flapping links
  - Labels are kept in the LIB even if one route goes down

Targeted LDP sessions

Example Cisco Router

MPLS LDP Discovery Targeted-hello Accept From Accept-LDP
!
IP Access-List Standard Accept-LDP
Permit 10.200.254.4

MPLS LDP Neighbor 10.200.254.1 Targeted LDP



LDP Authentication

- LDP sessions are TCP sessions
- TCP sessions can be attacked
- You can use Message Digest 5 (MD5)
  - Add a signature to the TCP segment
  - Use of configured passwords in both ends

Controlling Advertisement

- LDP lets you control the advertisement of labels
  - Only SOME labels to SOME LDP peers
  - Access list are commonly used for filtering
- Used to control number of labels advertised
  - LSR only advertises labels that are <u>in use</u>

Example of Ad filtering

```
hostname sydney
!
mpls ldp router-id Loopback0 force
no mpls ldp advertise-labels
mpls ldp advertise-labels for 1 to 2
mpls label protocol ldp
!
access-list 1 permit 10.200.254.3
access-list 1 permit 10.200.254.4
access-list 1 deny any
access-list 2 permit 10.200.254.5
access-list 2 deny any
```

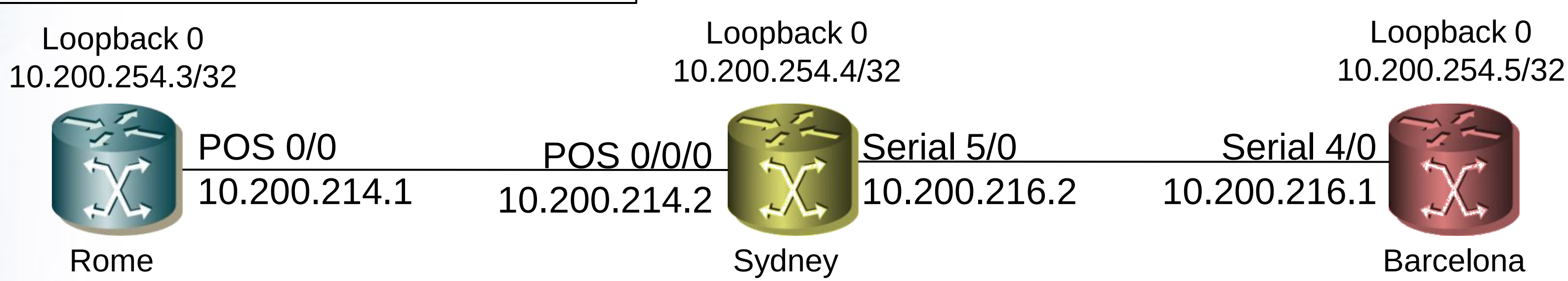
Filtered

~~LDP Label Mapping Message~~
<10.200.214.0/30, ->

~~LDP Label Mapping Message~~
<10.200.216.0/30, ->

LDP Label Mapping Message
<10.200.254.3/32, 21>

LDP Label Mapping Message
<10.200.254.4/32, imp-null>



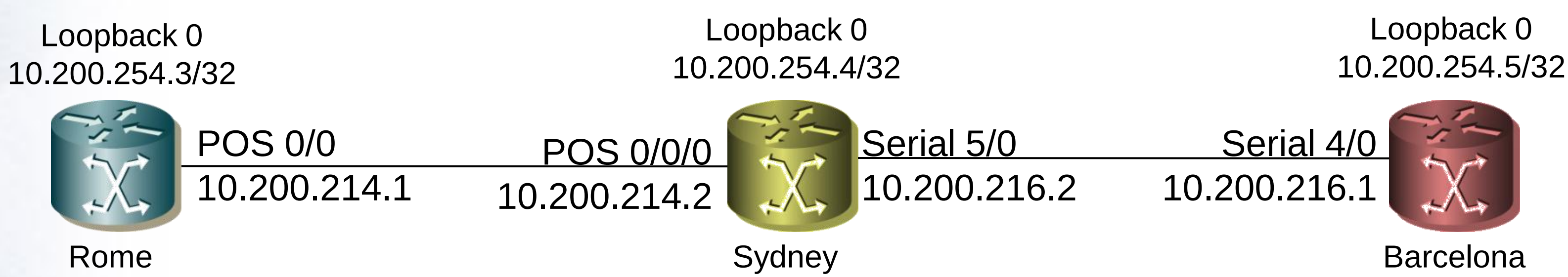
Inbound Label filtering

- Filtering of incoming label bindings from peer routers
- Limits number of labels stored in LIB
- Application in MPLS VPN
  1. Filter all routes but Loopback of PE
  2. Loopback usually = BGP Next-hop IP address
  3. Loopback label used to forward VPN traffic

Example Inbound filtering

```
hostname Barcelona
!
mpls ldp neighbor 10.200.254.4 labels-
accept 1
mpls ldp router-id Loopback0 force
mpls label protocol ldp
!
access-list 1 permit 10.200.254.4
access-list 1 permit 10.200.254.3
!
```

```
Barcelona#show mpls ldp bindings
lib entry: 10.200.211.0/24, rev 61
local binding: label: 26
lib entry: 10.200.254.2/32, rev 69
local binding: label: 27
lib entry: 10.200.254.3/32, rev 71
local binding: label: 19
remote binding: lsr: 10.200.254.4:0, label: 21
lib entry: 10.200.254.4/32, rev 28
local binding: label: 24
remote binding: lsr: 10.200.254.4:0, label: imp-
null
lib entry: 10.200.254.5/32, rev 7
local binding: label: imp-null
```

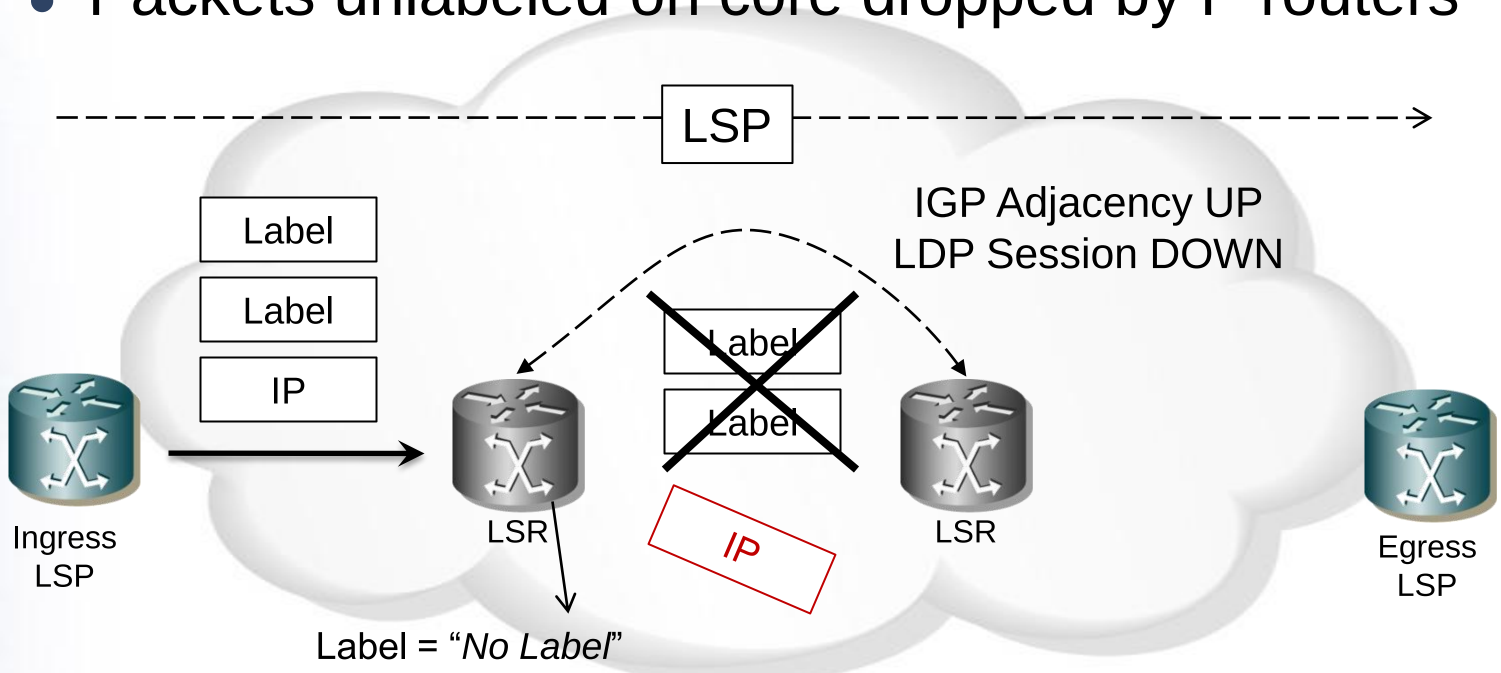


LDP-IGP Synchronization

- Lack of LDP-IGP Sync → Great problem
  - LDP and IGP must agree on the outgoing link
  - If LDP is broken BUT IGP is working
    - Packets can still be forwarded without Label
    - Unlabeled packets can be dropped if non-IPv4
      - IPv6, AToM, VPLS, MPLS VPNs → **labels needed!!**

LDP-IGP Synchronization

- Sync problems in a MPLS VPN
  - VRF routing table used to forward packets
  - User tables are only present on PE routers
  - Packets unlabeled on core dropped by P routers



A Solution

LDP-IGP Synchronization

- A solution is MPLS LDP-IGP Synchronization
  - Ensures that unlabeled packets are not forwarded if LDP is down in a link
  - If LDP is down in a link traffic is send over another link where LDP is enabled
- The problem does not affect BGP
  - BGP takes care of *binding advertisement* and *IP routing*

How Synch works?

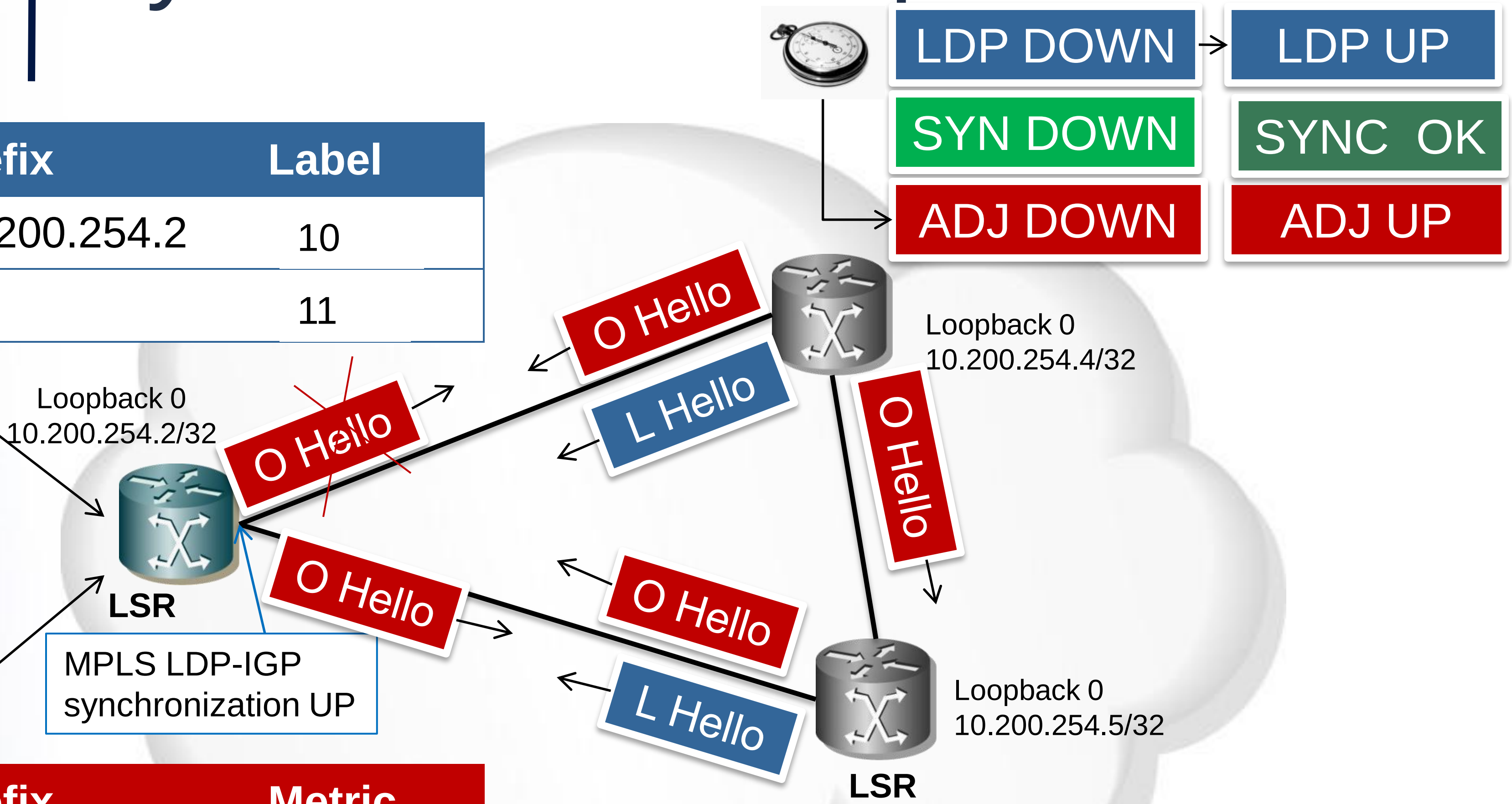
LDP-IGP Synchronization

- If LDP-IGP sync is active
  - When LDP is still down in a link
    - IGP announces that link with maximum metric
    - No path over that link will be used (if any other opt.)
    - In OSPF → Adjacency not established until LDP is up (no *Hello* sent on over the link)
    - If LDP is not up after some time Adjacency is established anyway (*Holddown Timer*)
  - When LDP is active and established
    - Normal IGP metric advertised on that link
    - Traffic is label-switched over that link

Synchronization operation

LDP

Prefix	Label
10.200.254.2	10
…	11



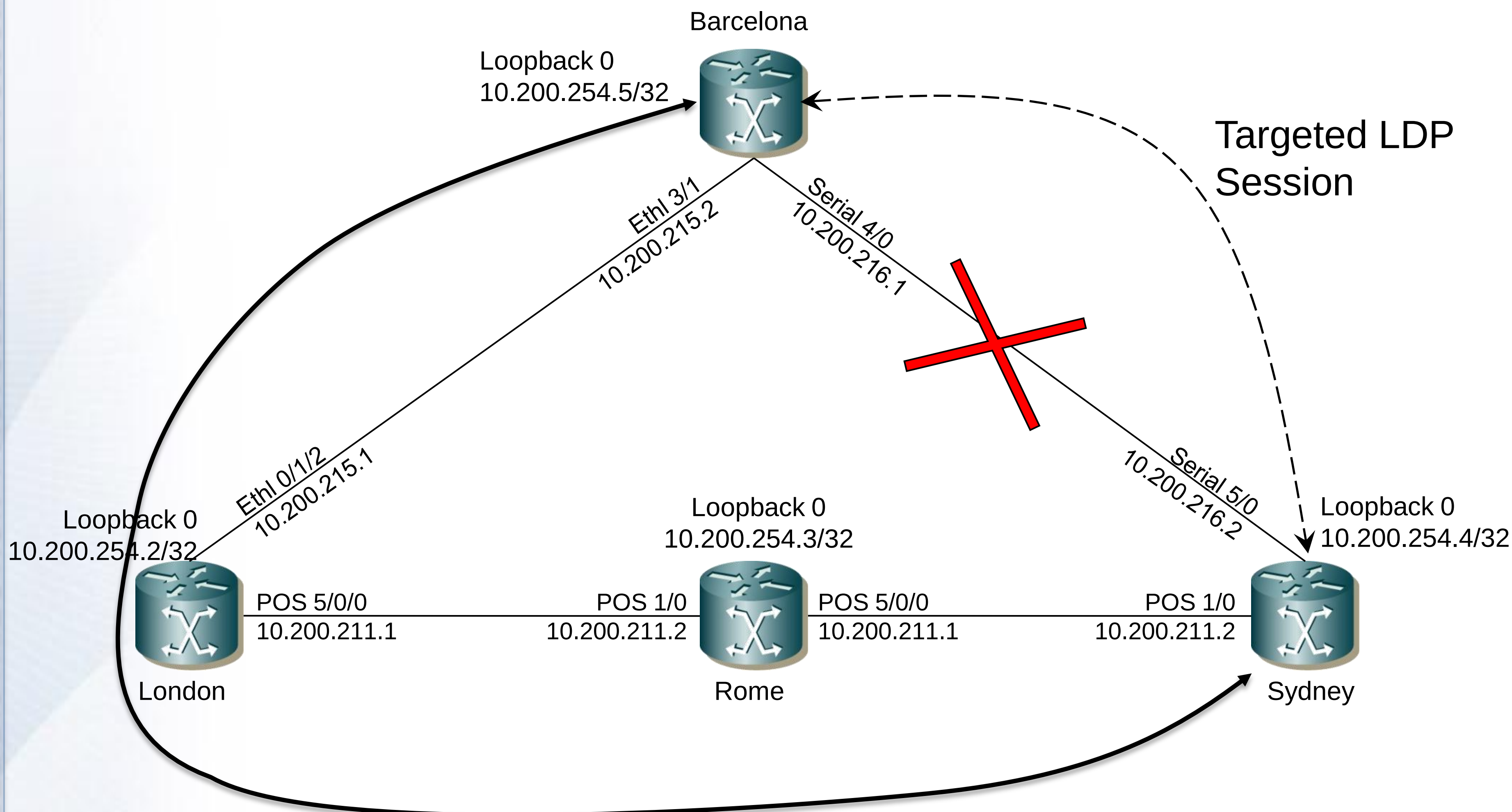
OSPF

Prefix	Metric
10.200.254.2	1
10.200.254.x	1

LDP Session Protection

- Flapping link have a high negative impact
- After a line goes down and up
  - LDP has to restart session
  - LDP has to exchange label bindings
  - IGP need to sync again
- Solution
  - Use of targeted session between neighbors
  - Targeted session is kept if there are alternative paths

LDP Session Protection



Review Questions

1. What is the fundamental purpose of LDP?
2. Name the four main functions that LDP takes care of.
3. How can you reduce the number of label bindings on an LSR?
4. What problem does MPLS LDP-IGP synchronization solve?
5. How many LDP sessions are established between two LSRs that have interfaces of which two links are LC-ATM links and four are frame links?
6. What do you need to configure to protect the LDP sessions against attacks?
7. What trick does MPLS LDP-IGP Synchronization employ to ensure to forward traffic while the LDP session is unsynchronized?
8. What does LDP Session Protection use to protect an LDP session?

Table of Contents

- Label Distribution Protocol
- **MPLS and ATM Architecture**
- Test Questions

Goals of the section

- ☑ The difference between MPLS operating in Frame mode and Cell mode
- ☑ How LDP advertises label bindings in ATM
- ☑ How the Label Virtual Circuits are set up
- ☑ How LDP behaves differently with ATM
- ☑ How LDP can provide loop detection
- ☑ What VC-Merge is, and what its benefit is for ATM LSRs

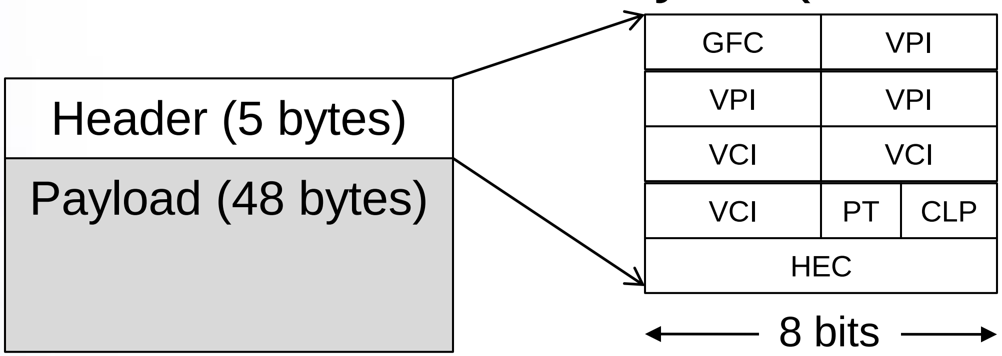
Label Distribution Protocol

- Introduction to ATM
- Label Encoding and advertisement
- LDP for LC-ATM
- Aggregation of Labels, VC-Merge

- Review Questions

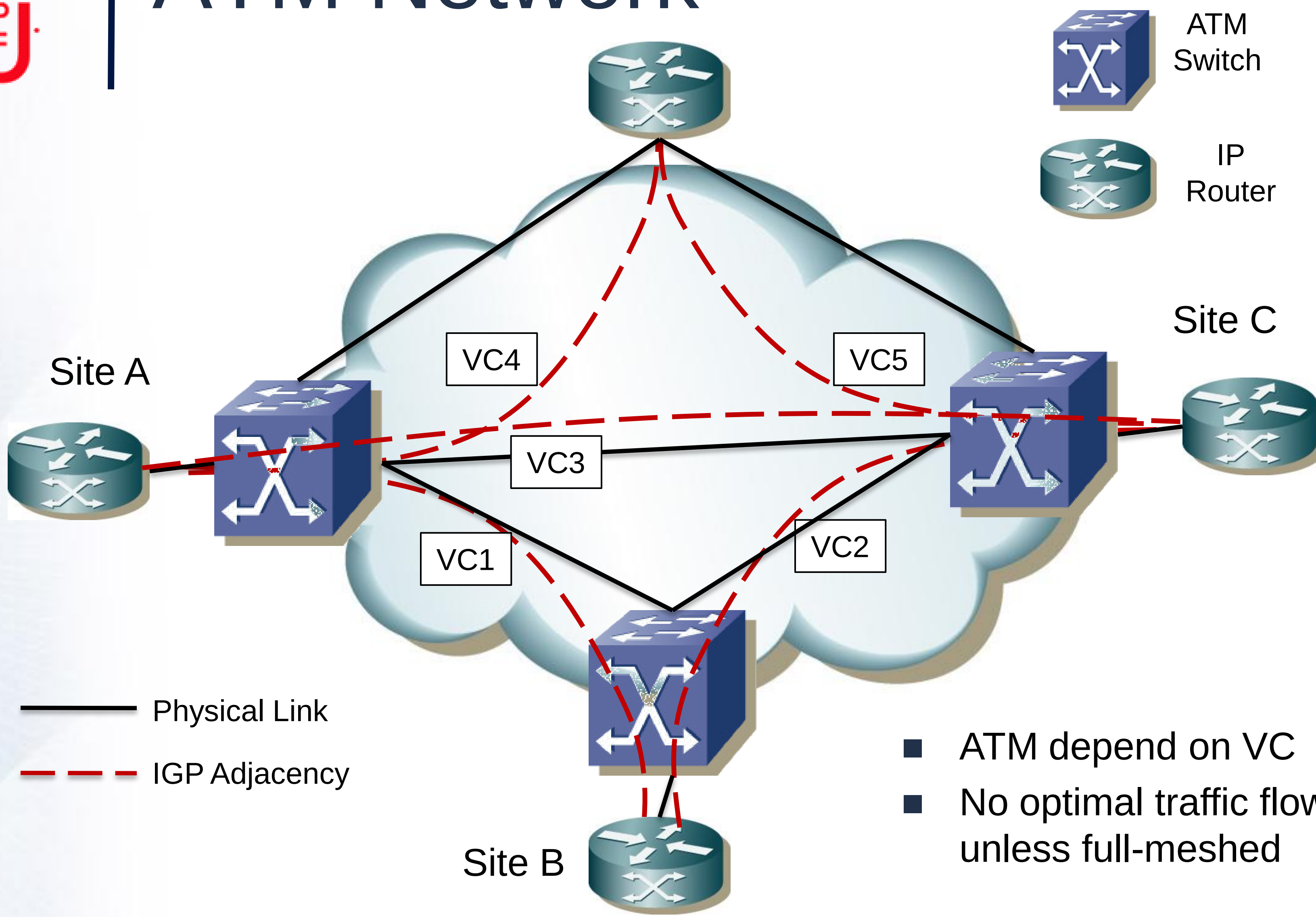
Brief Introduction to ATM

- **ATM UNI Cell:** 5 bytes (header) + 48 bytes data



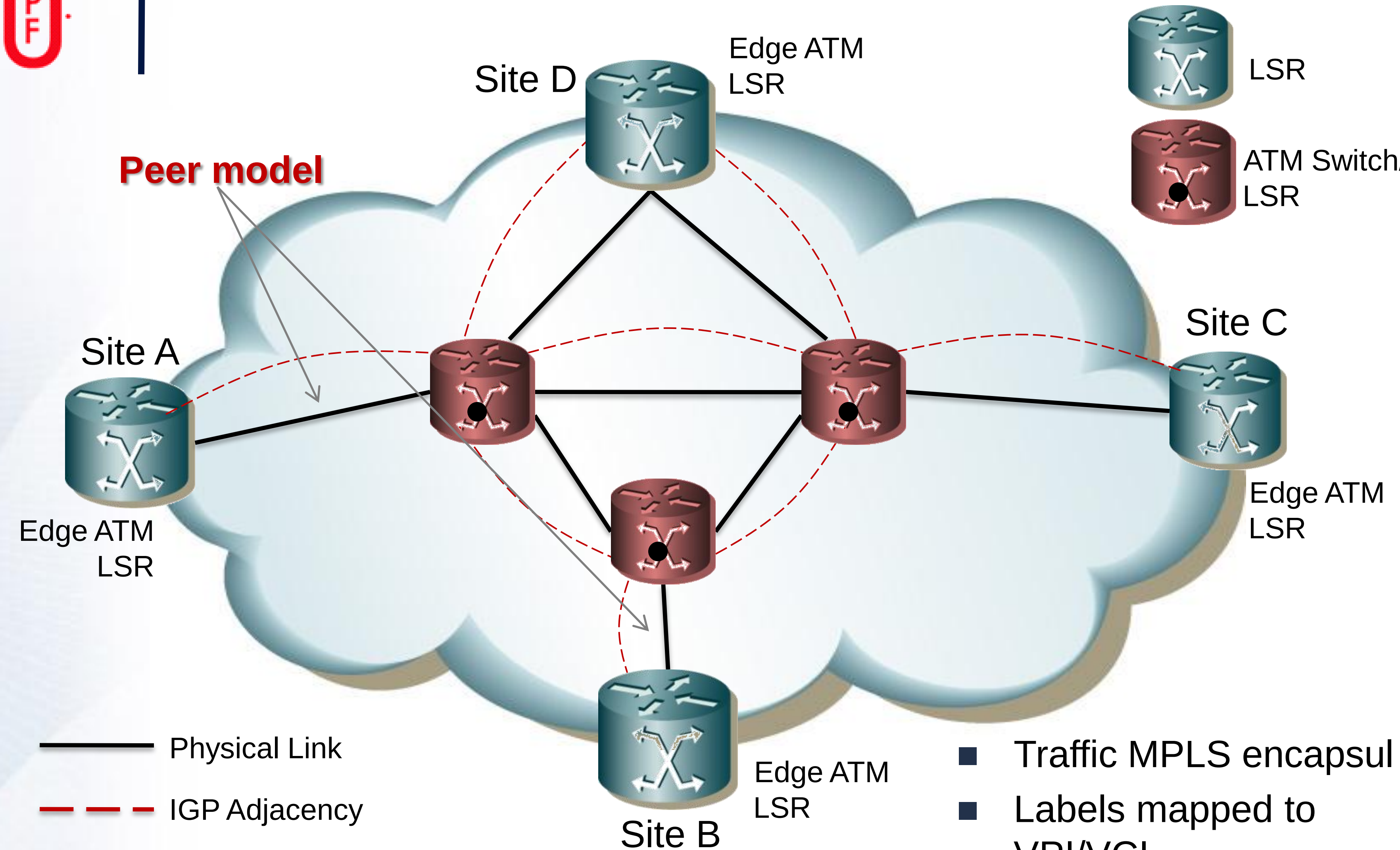
Field	Name	Length (bits)	Meaning
GFC	Generic Flow Control	4	Provides local functions
VPI	Virtual path identifier	8	Identifies the next destination of the cell
VCI	Virtual channel identifier	16	Identifies the next destination of the cell
PT	Payload type	3	Identifies the next destination of the cell
CLP	Cell Loss Priority	1	Indicates if cell discarded in the event of congestion
HEC	Header Error Control	8	Provides a checksum calculated on the header

ATM Network



- ATM depend on VC
- No optimal traffic flow unless full-meshed

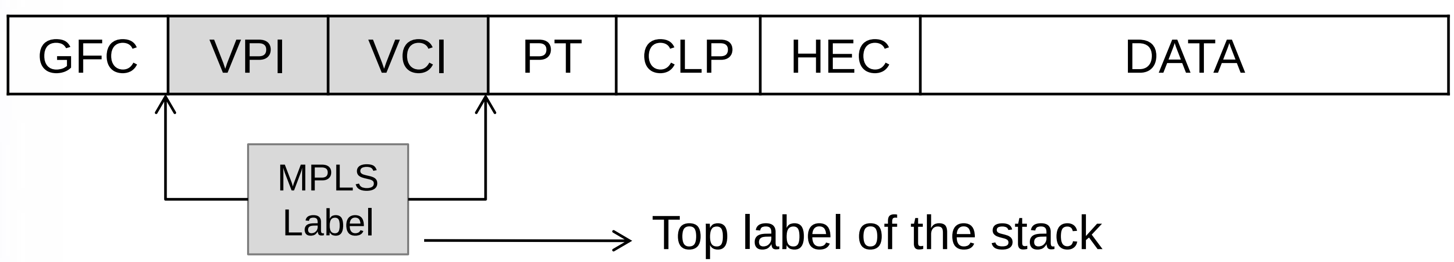
MPLS-ATM Network



- Traffic MPLS encapsul
- Labels mapped to VPI/VCI

MPLS-ATM Encapsulation

- Using ATM-LSRs requires
  - Encapsulation → Label mapped to VPI/VCI
  - A routing protocol
  - A label distribution protocol
  - Switching of ATM Cells
- Label Encoding



MPLS-ATM Advertisement

- IGP and LDP cannot run on ATM interface
- A control VC is needed for IGP and LDP
  - Allows ATM LSRs populate the LIB with bindings
  - Each label mapped to a VPI/VCI
  - A VC is built for each label (LVC)
- To create LVC configure interfaces LC-ATM
  - on ATM switches
  - on routers

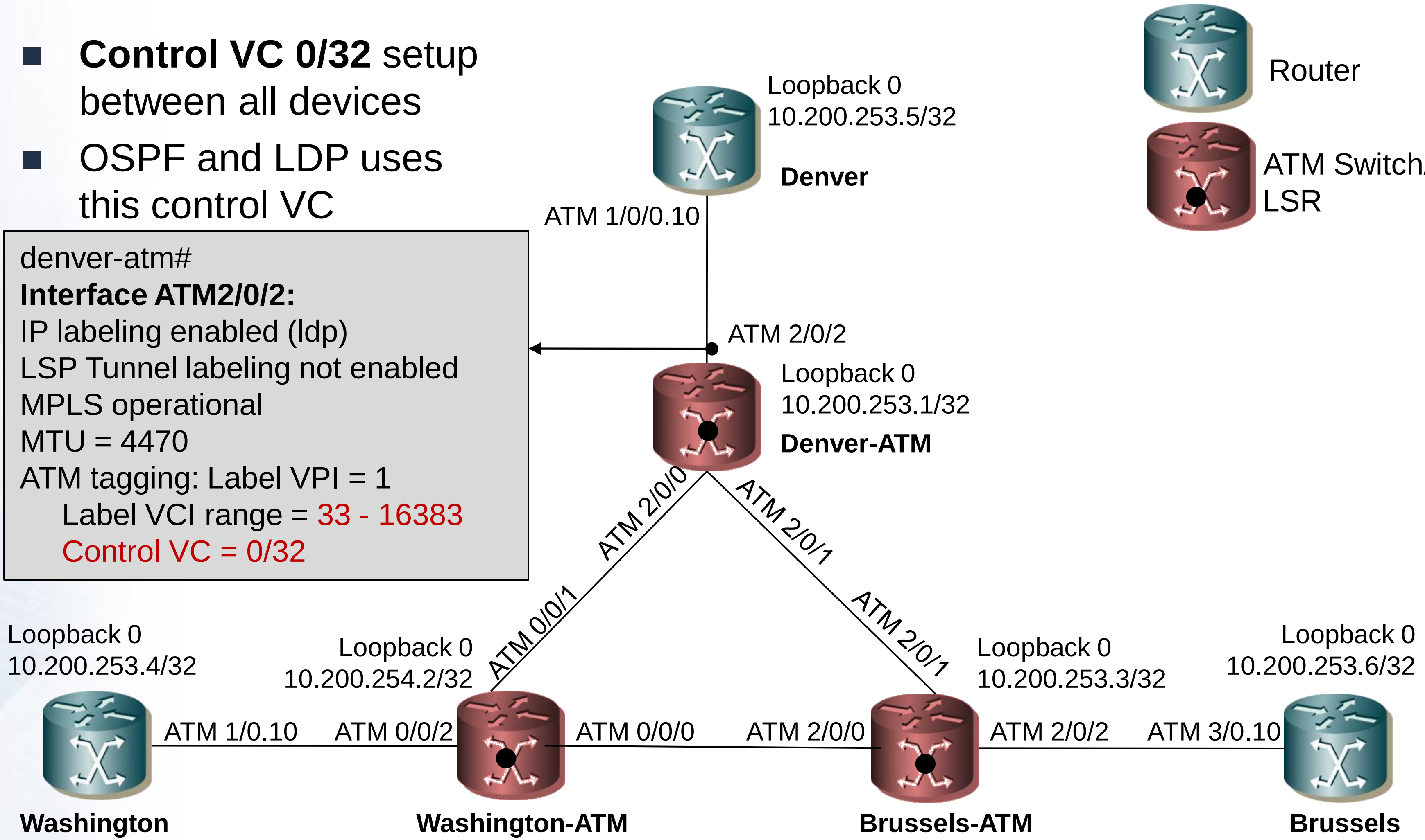
LC-ATM = Label Switching Controlled-ATM

LVC = Label Switching Controlled VC

Label advertisement

- **Control VC 0/32** setup between all devices
- OSPF and LDP uses this control VC

denver-atm#
Interface ATM2/0/2:
IP labeling enabled (ldp)
LSP Tunnel labeling not enabled
MPLS operational
MTU = 4470
ATM tagging: Label VPI = 1
Label VCI range = 33 - 16383
Control VC = 0/32

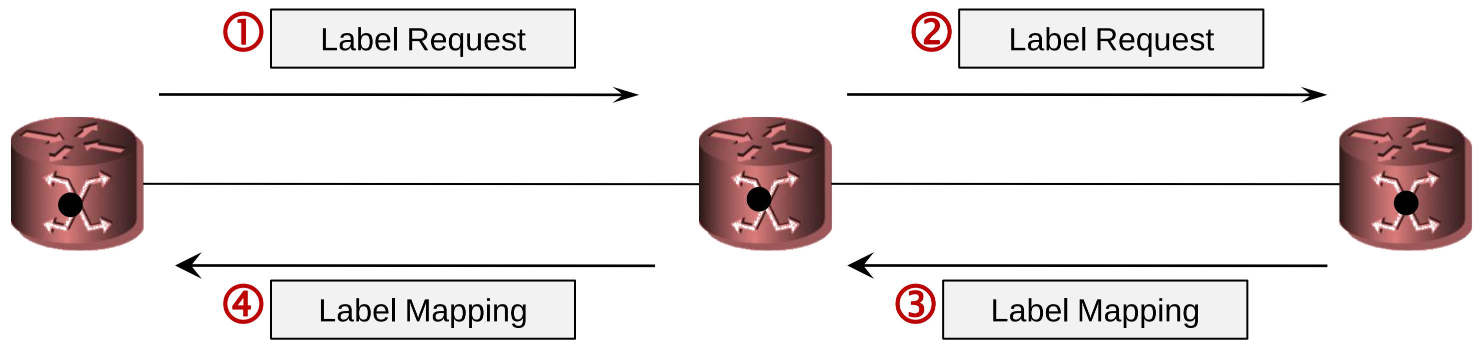


Downstream-on-Demand Label Advertisement

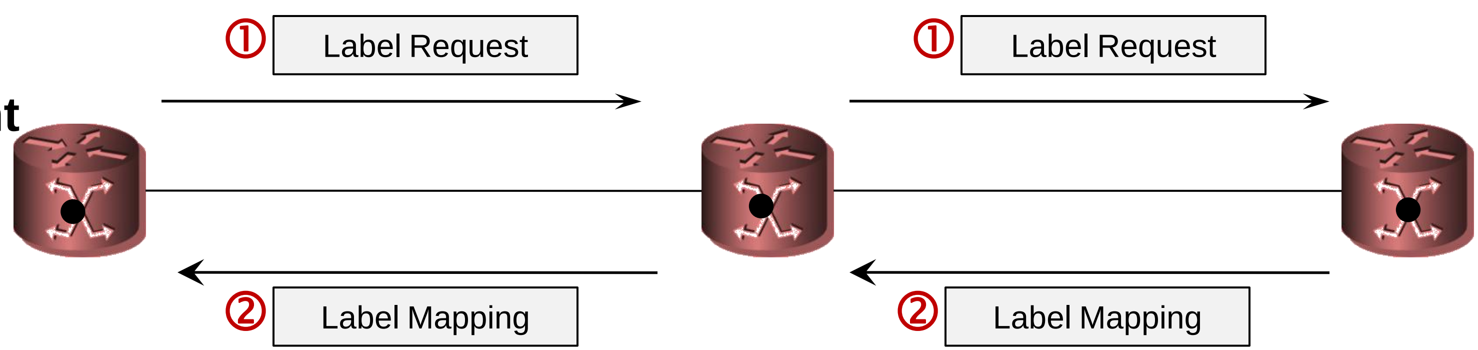
- ATM LSR operates in DoD Label advertisement mode
  - Upstream LSR requests the downstream LSR for a label for a prefix
- ATM LSRs use Ordered LSP Control mode
- Routers use Independent LSP Control mode

LDP Control Mode

Ordered Control mode

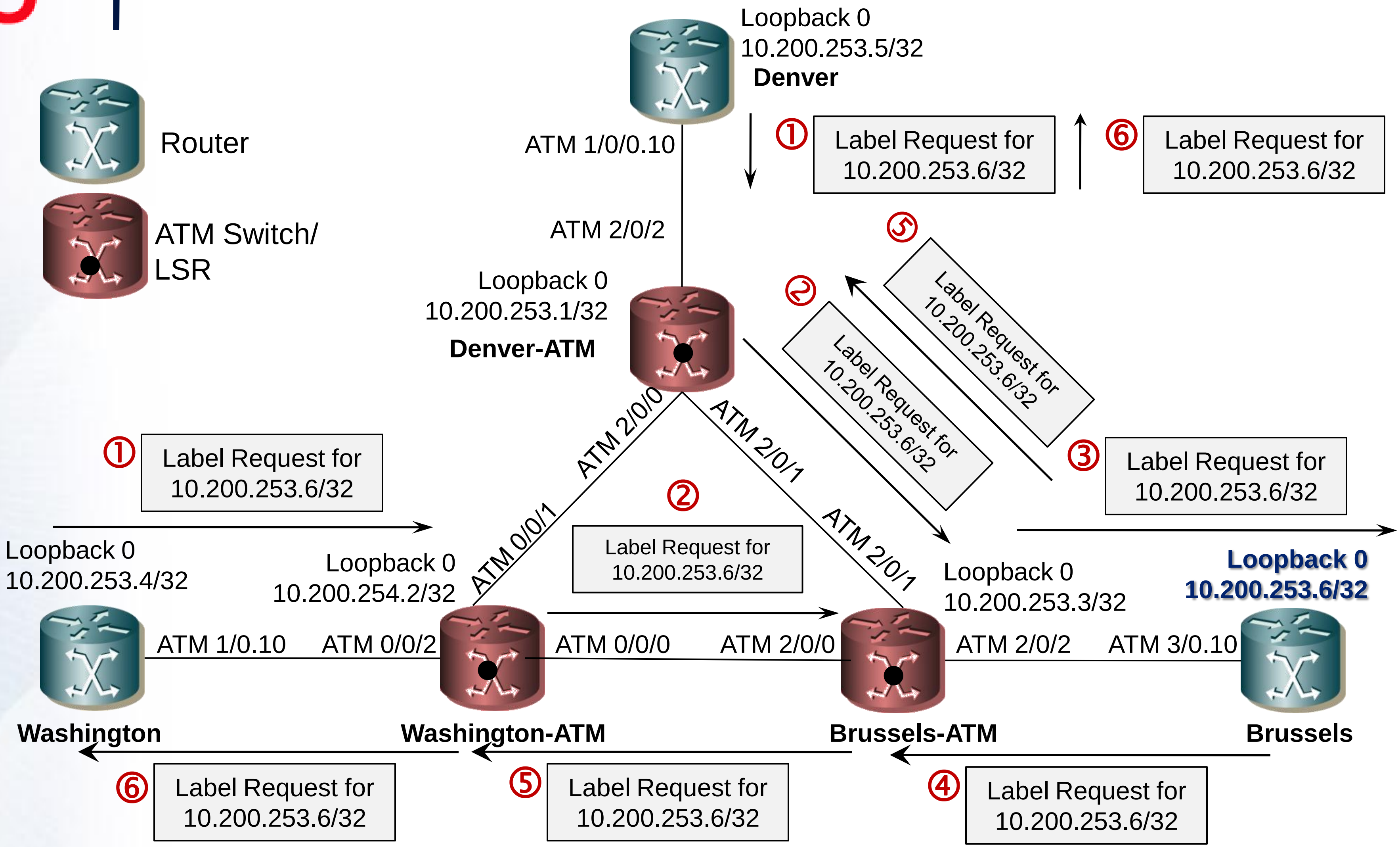


Independent Control mode



Example using MPLS-ATM

DoD Label Ad with Ordered LSP Control Mode



MPLS label bindings

denver-atm#show mpls ip binding

```
10.200.253.2/32
        in label:       16
        in vc label:    1/39    lsr: 10.200.253.5:1    ATM2/0/2
                        Active transit
        out vc label:   1/35    lsr: 10.200.253.2:1    ATM2/0/0
                        Active transit
10.200.253.3/32
        in label:       17
        in vc label:    1/91    lsr: 10.200.253.5:1    ATM2/0/2
                        Active transit
        out vc label:   1/33    lsr: 10.200.253.3:2    ATM2/0/1
                        Active transit
10.200.253.4/32
        in label:       18
        in vc label:    1/41    lsr: 10.200.253.5:1    ATM2/0/2
                        Active transit
        out vc label:   1/36    lsr: 10.200.253.2:1    ATM2/0/0
                        Active transit
```

LDP for LC-ATM

- Label Space *per interface*
  - LDP ID = *router-id:labelSpace_number*

washington-atm#show mpls ldp discovery
Local LDP Identifier:
10.200.253.2:0
Discovery Sources:
Interfaces:
ATM0/0/0 (ldp): xmit/recv
LDP Id: 10.200.253.3:1
ATM0/0/1 (ldp): xmit/recv
LDP Id: 10.200.253.1:1
ATM0/0/2 (ldp): xmit/recv
LDP Id: 10.200.253.4:1
ATM0/0/3 (ldp): xmit/recv
LDP Id: 10.200.253.3:4

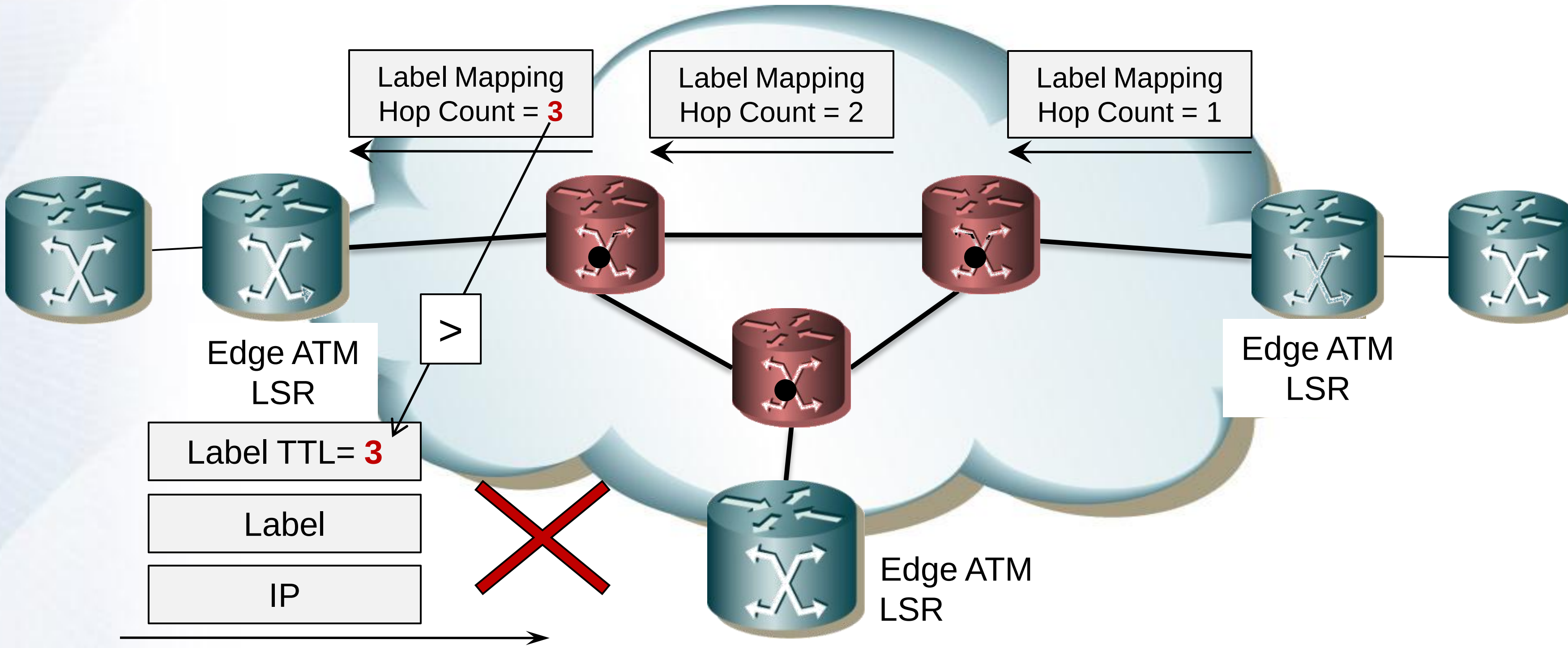
Washington-ATM and Brussels-ATM have two interfaces between them and two label spaces **:1** and **:4**

Loop detection

- ATM-LSR Forward cells → no TTL field!
- Use of *Hop Count TLV* and *Path Vector TLV* in LDP
- Hop Count TLV
  - Number of LSRs that an LDP message has traversed
  - A *maximum_number_LSR* is configured
- Path Vector TLV
  - List the LSR that an LDP message has traversed
  - LSR IDs are added to the list each hop
  - Loop detected when a two LSR IDs are repeated

TTL Manipulation

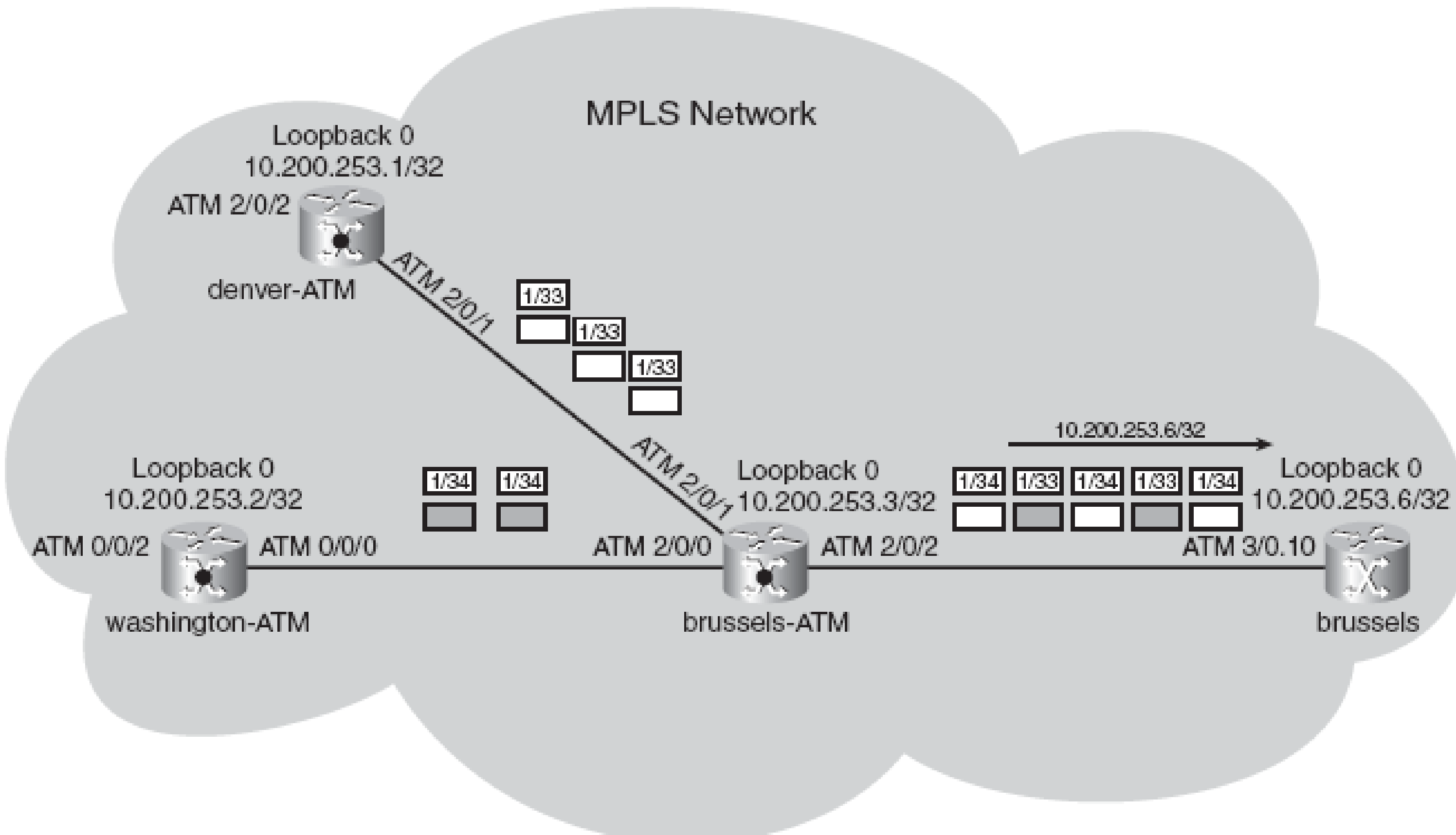
- ATM-LSR cannot decrement TTL value
- We can use hop-count technique before a packet enters ATM domain



Aggregate of Labels

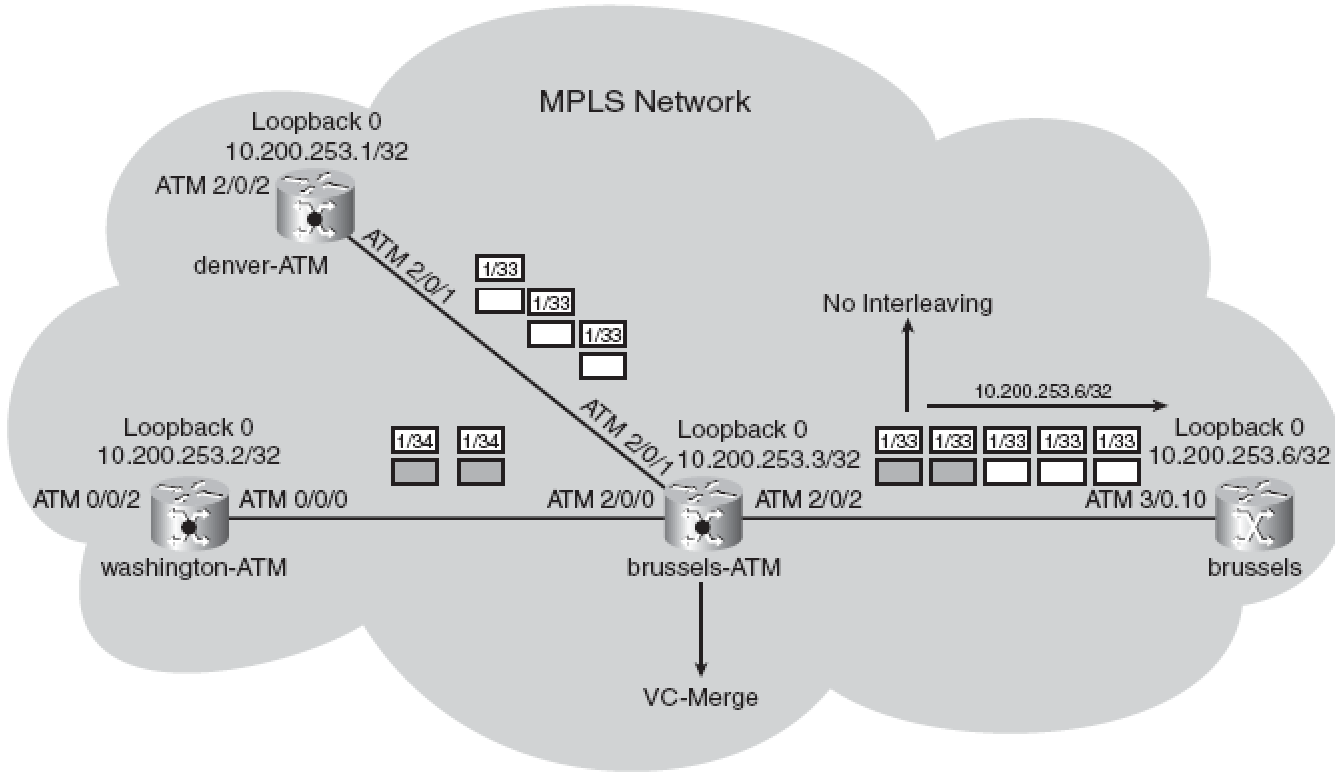
- Aggregation operation
  - Several IPv4 addresses summarized into one prefix
    - 192.168.0.0/24
    - 192.168.1.0/24
    - 192.168.254.0/24 → 192.168.0.0/16
  - **Do not do aggregation** on ATM LST
    - Label packets need to be unlabelled → we need all the ATM cells to reconstruct packet
    - An IP lookup to decide the Label
    - Chop the packet into cells and add the new label

VC Merge



MPLS Network
Loopback 0
10.200.253.1/32
ATM 2/0/2
denver-ATM
ATM 2/0/1
1/33
1/33
1/33
ATM 2/0/1
Loopback 0
10.200.253.2/32
ATM 0/0/2
ATM 0/0/0
washington-ATM
1/34
1/34
ATM 2/0/0
Loopback 0
10.200.253.3/32
brussels-ATM
ATM 2/0/2
10.200.253.6/32
1/34
1/33
1/34
1/33
1/34
Loopback 0
10.200.253.6/32
ATM 3/0.10
brussels

VC Merge


MPLS Network
Loopback 0
10.200.253.1/32
ATM 2/0/2
denver-ATM
ATM 2/0/1
1/33
1/33
1/33
No Interleaving
10.200.253.6/32
Loopback 0
10.200.253.2/32
ATM 0/0/2
ATM 0/0/0
washington-ATM
1/34
1/34
ATM 2/0/1
Loopback 0
10.200.253.3/32
ATM 2/0/0
ATM 2/0/2
brussels-ATM
1/33
1/33
1/33
1/33
1/33
Loopback 0
10.200.253.6/32
ATM 3/0.10
brussels
VC-Merge

Review Questions

1. In what ways is an ATM LSR different from a frame-based LSR?
2. What is the default control VC for LDP?
3. What is the preferred control mode for LDP on the ATM LSRs?
4. Name two ways that LDP can detect loops.
5. Which two features must an ATM switch have in the control plane to become an ATM LSR?
6. Which label space is used on an LC-ATM interface?
7. What would be the reason to disable the head end VCs on an LSC?
8. What is the advantage and disadvantage of VC-Merge?

Test Questions

1. **It is an MPLS requirement that control-plane traffic be exchanged using ____________.**
   A. Broadcast
   B. Unlabeled IP
   C. Multicast
   D. Labeled IP over VC 0/32
2. **Routers with ATM interfaces run ____________ MPLS.**
   A. Frame-mode
   B. Cell-mode
3. **An LSC communicates with an ATM-LSR on which of the following VCs?**
   A. 0/1
   B. 0/7
   C. 0/32
   D. 0/4096

Test Questions

4. **Which of the following methods is used by cell-mode MPLS to bind labels? (Choose two.)**
   - A. ordered control
   - B. independent control
   - C. downstream-on-demand
   - D. unsolicited downstream
5. **Cell-mode MPLS does not switch traffic based on a label but instead uses the ____________ values.**
   - A. SVC/PVC
   - B. DLCI
   - C. VCI/VIP
   - D. VPI/VCI
6. **ATM-LSRs use which of the following signaling protocols to exchange labels?**
   - A. UNI
   - B. MNI
   - C. PNNI
   - D. LDP

ANSWER TO REVIEW QUESTIONS

Review Questions

1. What is the fundamental purpose of LDP?
2. Name the four main functions that LDP takes care of.
3. How can you reduce the number of label bindings on an LSR?
4. What problem does MPLS LDP-IGP synchronization solve?
5. How many LDP sessions are established between two LSRs that have interfaces of which two links are LC-ATM links and four are frame links?
6. What do you need to configure to protect the LDP sessions against attacks?
7. What trick does MPLS LDP-IGP Synchronization employ to ensure to forward traffic while the LDP session is unsynchronized?
8. What does LDP Session Protection use to protect an LDP session?

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