# MikroTik RouterOS Training

# Inter-Networking

## Overview

- BGP
  - BGP Basics (iBGP, eBGP)
  - Distribution, filtering and BGP attributes
- MPLS
  - Introduction to MPLS
  - LDP
  - L2 and L3 VPN's
  - Traffic Engineering

## Lab Setup

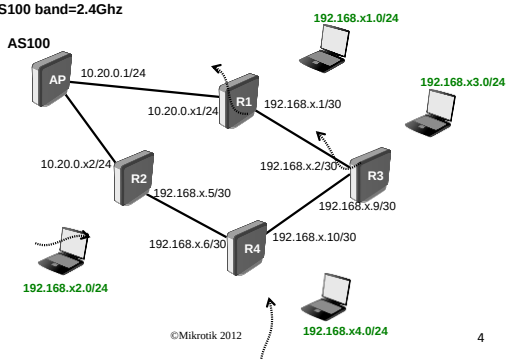
- Divide in groups by four
- Make network setup as illustrated in next slide
- R1 and R2 routes connect to AP with SSID AS100 in 2.4Ghz band
- Each router has local network 192.168.xy.0/24 where:
  - X-group number
  - Y-Routers number

## Lab Setup

**X** – group number

AP SSID=**AS100 band=2.4Ghz**



Border Gateway Protocol

(BGP)

## Autonomous system

- Set of routers under a single administrative control
- Routing exchange:
  - Routers within AS use common IGP
  - Routers between ASs use EGP
- Has its own number (ASN)
  - Supports 16-bit value and 32-bit value
  - Numbers 64 512 – 65 534 reserved for private use

## BGP Basics

- Stands for Border Gateway Protocol
- Designed as Inter-AS routing protocol
- Network topology is not exchanged, only reachability information.
- Only protocol that can handle Internet's size networks
- Uses path vector algorithm

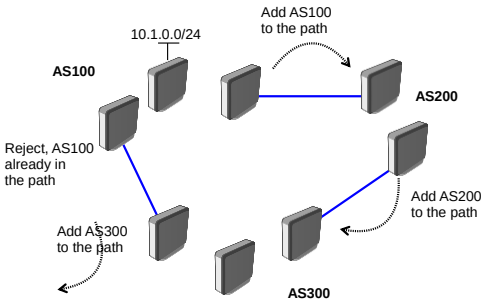



## Path Vector Implementation

- Treats whole AS as a single point in the path
- Prefix is advertised with the list of ASs along the path called AS path
- Hides network topology within an AS
- Cannot provide loopfree routing within an AS




## Path Vector Implementation







## BGP Capabilities

- BGP Speaker advertises supported capability codes
- If received capability is not supported, remote peer sends back notification
- BGP speaker attempts to peer without unsupported capability
- Some of RouterOS advertised capabilities:
  - Route refresh
  - Multi-protocol extension
  - 4-byte AS support




## BGP Transport

- Operates by exchanging NLRI (network layer reachability information).
- NLRI includes a set of BGP attributes and one or more prefixes with which those attributes are associated
- Uses TCP as the transport protocol (port 179)
- Initial full routing table exchange between peers
- Incremental updates after initial exchange (maintains routing table version)




## Packet format

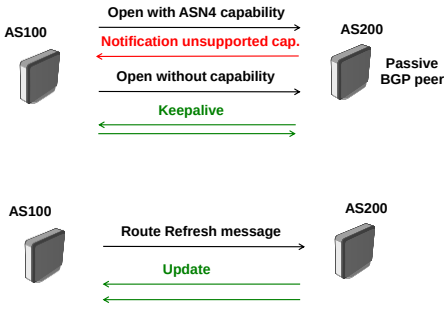
- Packet contains four main fields:
  - Marker (128bits) – used for authentication
  - Length (16bits)
  - Type (8bits) – BGP message type
  - Message body

## BGP message types

- Four message types:
  - Open – First message sent after TCP connection establishment, contains capability list. Confirmed by keepalive.
  - Keepalive – does not contain data, sent to keep hold timer from expiring
  - Update – actual route updates. Contains:
    - NLRI
    - Path attributes
  - Notification – sent when error condition occurs, contains error code and sub-code




## BGP session and updates







## Networks

- Indicates what networks BGP should originate from the router.
- By default network is advertised only if corresponding route is present in routing table
- Synchronization can be turned off if:
  - Your AS does not provide transit service
  - All the transit routers run BGP
- Disabling sync allows BGP to converge faster.
- Sync can be dangerous if routes are flapping a lot.
- Configurable from **`/routing bgp network`**




## Enable BGP

```
/routing bgp instance
set default as=300 router-id=10.10.10.4

/routing bgp peer
add instance=default remote-address=10.10.10.1 remote-as=3000
```

If **router-id** is not specified, it is automatically set to least IP address on the router.

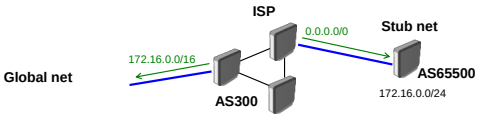
Verify BGP connectivity. Any state other than **established** indicates that routers can not become neighbors (use *print status* for more details)

```
[admin@R1] /routing bgp peer> print
Flags: X - disabled, E - established
 #    INSTANCE        REMOTE-ADDRESS                REMOTE-AS
0 E default          10.10.10.1                    3000
```




## Stub network Scenarios

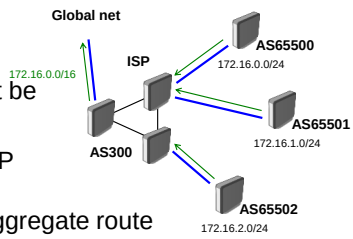
- Single homed
  - Private ASN is used (>64511)
  - ISP originates only default route
  - Actually no need for BGP
  - Upstream ISP advertises networks
  - Stub network has the same policy as ISP







## Private AS Removal




- Private AS cannot be leaked to public
- Available for eBGP neighbors
- Announce only aggregate route
- Use following command

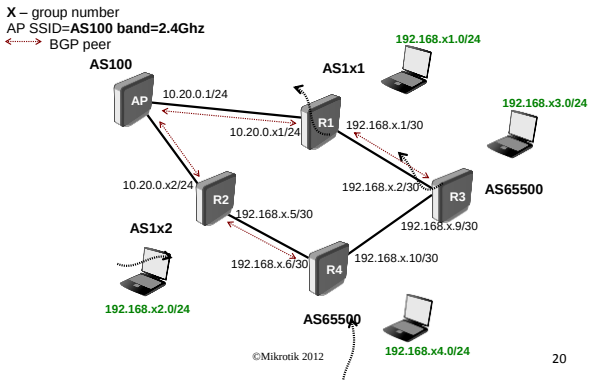
```
/routing bgp peer
set <peer-name> remove-private-as=yes
```

## BGP Lab I

- Create BGP network setup as illustrated in next slide:
  - BGP peer from R1 and R2 to AP
  - BGP peer from R2 to R4
  - BGP peer from R1 to R3
- Advertise your local network
- Private ASN should be removed
- Originate default route to private AS routers




## BGP Lab I

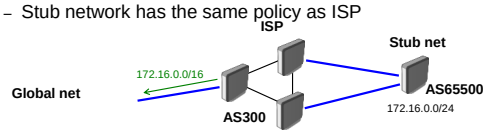






## Stub network Scenarios

- Multihomed
  - Private ASN is used
  - Can be used:
    - As main/backup link
    - Load sharing
  - Upstream ISP advertises networks
  - Stub network has the same policy as ISP

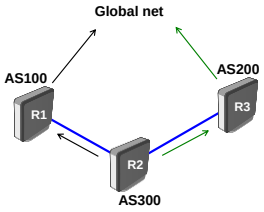






## Non-stub Scenarios

- Need to obtain AS number from ISP or RIR
- Address range from Regional Internet Registry
- Routing policy independent from ISPs
- Can be used:
  - As main/backup link
  - Load sharing
  - More advanced routing policies







## BGP and connection tracking

- Connection tracking is unable to keep valid track of connections with multi-homed BGP.
- Packets related to one connection can travel through different paths
  - Do not drop invalid connections in firewall
- Con-track should be turned off for better performance

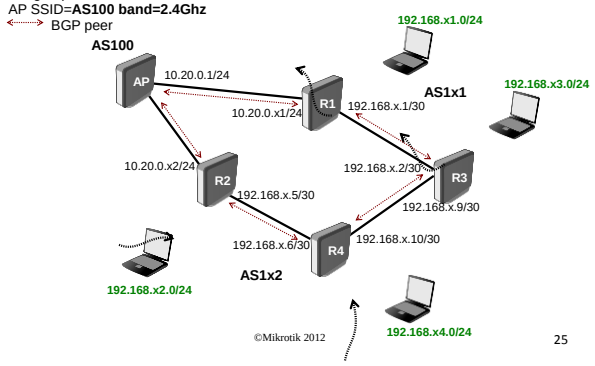



## BGP Lab II

- Add R3 to the same AS as R1
- Add R4 to the same AS as R2
- Make BGP peer between R4 and R3
- Set up OSPF between routers in the same AS
- Set OSPF to distribute connected routes
- Announce both local networks from AS

# BGP Lab II

**X** – group number
AP SSID=**AS100 band=2.4Ghz**
BGP peer







# BGP Lab II

```
[admin@R1] /ip route> print
Flags: X - disabled, A - active, D - dynamic,
C - connect, S - static, r - rip, b - bgp, o - ospf, m - mme,
B - blackhole, U - unreachable, P - prohibit
 #      DST-ADDRESS        PREF-SRC        GATEWAY     DISTANCE
 0 ADb  0.0.0.0/0                          10.20.0.1         20
 1 ADC  10.20.0.0/24       10.20.0.11      R1_AP              0
 2 ADC  192.168.1.0/30     192.168.1.1     R1_R3              0
 3 ADo  192.168.1.8/30                     192.168.1.2      110
 4 ADC  192.168.11.0/24    192.168.11.0    local              0
 5  Db  192.168.11.0/24                    192.168.1.2      200
 6 ADb  192.168.12.0/24                    192.168.1.10     200
 7  Db  192.168.12.0/24                    10.20.0.12        20
 8 ADo  192.168.13.0/24                    192.168.1.2      110
 9  Db  192.168.13.0/24                    192.168.1.2      200
10 ADb  192.168.14.0/24                    192.168.1.10     200
11  Db  192.168.14.0/24                    10.20.0.12        20
```




# BGP Lab II

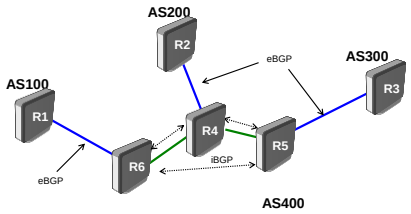
```
[admin@R3] /ip route> print
Flags: X - disabled, A - active, D - dynamic,
C - connect, S - static, r - rip, b - bgp, o - ospf, m - mme,
B - blackhole, U - unreachable, P - prohibit
 #      DST-ADDRESS        PREF-SRC        GATEWAY     DISTANCE
 0 ADb  0.0.0.0/0                          192.168.1.1       200
 1 ADo  10.20.0.0/24                       192.168.1.1       110
 2 ADC  192.168.1.0/30     192.168.1.2     R3_R1              0
 3 ADC  192.168.1.8/30     192.168.1.9     R3_R4              0
 4 ADo  192.168.11.0/24                    192.168.1.1       110
 5  Db  192.168.11.0/24                    192.168.1.1       200
 6 ADb  192.168.12.0/24                    192.168.1.10      20
 7 ADC  192.168.13.0/24    192.168.13.0    local              0
 8  Db  192.168.13.0/24                    192.168.1.1       200
 9 ADb  192.168.14.0/24                    192.168.1.10      20
```

BGP redistributes only best route. Since on R1 best route is one received from R3, router R1 does not redistribute .12/024 and .14.0/24 back to R3




# Interior and Exterior BGP

- **iBGP** – peering between routers inside an AS
- **eBGP** – peering between routers from different ASs





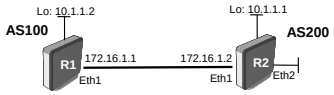


# eBGP

- Almost always formed between directly connected peers (AS edge routers).
- Multi-hop configuration is required if peers are not directly connected
- Adds AS to advertised prefix's path
- By default Next-hop is changed to self




# eBGP Multihop example




```
/routing bgp peer
add remote-address=10.1.1.x remote-as=x multihop=yes \
   update-source=lo
```

Configuration requires static routes or enabled IGP so that the neighbors can reach each other.

Setting eBGP to Loopback addresses can protect BGP from DOS attacks

## iBGP

- Next-hop is not changed by default:
  - Uses IGP (RIP,OSPF,static) to ensure network reachability within an AS
- Attributes learned from iBGP are not changed to impact the path selection to reach outside network
- AS path is not manipulated
- Provides ways to control exit point from an AS
- Received external route from iBGP peer is not propagated to other iBGP peers:
  - Requires full mesh between iBGP peers.




```
[admin@R1] /ip route> print
Flags: X - disabled, A - active, D - dynamic,
C - connect, S - static, r - rip, b - bgp, o - ospf, m - mme,
B - blackhole, U - unreachable, P - prohibit
 #      DST-ADDRESS         PREF-SRC        GATEWAY      DISTANCE
 0 ADb  0.0.0.0/0                           10.20.0.1    20
 1 ADb  10.1.101.0/24                       10.20.0.1    20
 2 ADC  10.20.0.0/24        10.20.0.11      ether1       0
 3 ADC  192.168.1.0/30      192.168.1.1     ether2       0
 4 ADC  192.168.11.0/24     192.168.11.1    dummy        0
 5  Db  192.168.12.0/24                     192.168.1.10 200
 6 ADb  192.168.12.0/24                     10.20.0.12   20
 7 ADb  192.168.13.0/24                     192.168.1.2  200
 8  Db  192.168.14.0/24                     192.168.1.10 200
 9 ADb  192.168.14.0/24                     10.20.0.12   20
```

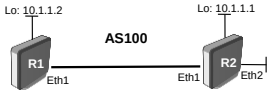
8 Db dst-address=192.168.14.0/24 gateway=192.168.1.10
gateway-status=192.168.1.10 unreachable distance=200 scope=40
target-scope=30 **bgp-as-path="112"** bgp-local-pref=100 bgp-origin=igp
received-from=peer2

9 ADb dst-address=192.168.14.0/24 gateway=10.20.0.12
gateway-status=10.20.0.12 reachable ether1 distance=20 scope=40
target-scope=10 **bgp-as-path="100,112"** bgp-origin=igp
received-from=peer1




## Loopback

- Eliminates dependency from physical interface to make TCP connection.
- Mostly used between iBGP peers
- In RouterOS empty bridge can be used as loopback




```
/interface bridge add name=lo
/ip address add address=10.1.1.x/32 interface=lo
/routing bgp peer
add remote-peer=10.1.1.x remote-as=100 update-source=lo
```




## BGP Lab III

- Improve your setup by using loopback addresses between iBGP peers
  **10.255.x.y/32**, where
  x – group number
  y – router's number
- Add loopback address to OSPF networks
- Set loopback address as ospf and bgp router-id




## Route Distribution

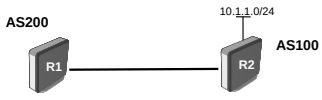
- IGP (Static, OSPF, RIP, connected) routes can be redistributed

```
/routing bgp instance
set default redistribute-static=yes
set default redistribute-ospf=yes
```

- Prefix origin is “incomplete”
- Risk of advertising all IGP routes
- Always use routing filters to avoid unwanted route advertisements




## Distribution Example




```
/ip route add dst-address=10.1.1.0/24 type=unreachable
/routing bgp instance set default redistribute-static=yes
```

- Packets will be ceased unless more specific route is present
- Good way to advertise supernet

## Routing Filters

- Main tool to control and modify routing information
- Organized in chains similar to firewall
- Specify in BGP peer's configuration which chains to use or BGP instance out filter
- Prefix passes instance chain, then moves to peer's chain

```
/routing bgp peer set 0 in-filter=bgp-in out-filter=bgp-out

/routing filter add chain=bgp-out prefix=10.1.1.0/24 \
  action=discard invert-match=yes
```




## Filter Chain example

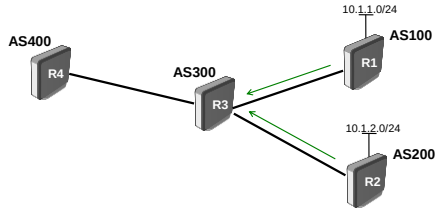
```
/routing bgp instance set default out-filter=bgp-o
/routing bgp peer set peer1 out-filter=bgp-peer-o

/routing filter
add chain=bgp-o prefix=10.1.1.0/24 action=accept \
 set-bgp-communities=30:30
add chain=bgp-o action=discard
add chain=bgp-peer-o prefix=10.1.1.0/24 action=passthrough \
 set-out-nexthop=192.168.99.1
```

3 **ADb** dst-address=10.255.1.2/32 gateway=10.20.0.12
**gateway-status=192.168.99.1** reachable ether2 distance=20 scope=40
target-scope=10 bgp-as-path="112" bgp-origin=igp
**bgp-communities=30:30** received-from=peer2




## Prefix filtering




```
# config on R3
/routing bgp peer set peer1 out-filter=bgp-out

/routing filter add prefix=10.1.0.0/16 prefix-length=16-32 \
   chain=bgp-out action=discard
```




## AS Path filtering

- Can be configured to allow updates only to/from certain AS
- Supports regular expressions
  - "." - any single character
  - "^" - start of the as-path
  - "$" - end of the as-path
  - "_" - matches comma, space, start and end of as-path

```
# config on R3

/routing filter add chain=bgp-out action=discard \
   bgp-as-path=_200_
```




## BGP Soft Reconfiguration

- When **action=discard** is used, routes are not updated after filter change.
- Solution
  - Use **action=reject** to keep routes in the memory
  - Dynamic (Peer must support refresh capability):
    - Peer refreshes the routes after the changes are done.
    - No additional memory is used
    - It is not done automatically - need to run **"refresh"** command




## BGP Lab IV

- Set up routing filters in the way that:
  - R1 does not receive 192.168.x2.0/24 prefix via AP
  - R2 does not receive 192.168.x1.0/24 prefix via AP
  - R3 does not receive 192.168.x4.0/24 prefix from R4
  - R4 does not receive 192.168.x3.0/24 prefix from R3

## BGP Lab IV

Lets look at R3. If set up properly traceroutes to network x2 should go over R4 and traceroutes to x4 should go over AP

```
[admin@R3] /ip address> /tool traceroute 192.168.12.1 \
       src-address=192.168.13.1
 # ADDRESS                          RT1   RT2   RT3   STATUS
 1 192.168.1.6                      4ms   4ms   4ms
 2 192.168.12.1                     3ms   4ms   4ms

[admin@R3] /ip address> /tool traceroute 192.168.14.1 \
       src-address=192.168.13.1
 # ADDRESS                          RT1   RT2   RT3   STATUS
1 192.168.1.1                      2ms   2ms   2ms
 2 10.20.0.12                       3ms   4ms   4ms
 3 192.168.14.1                     6ms   6ms   6ms
```




## BGP decision algorithm

- BGP uses single best path to reach the destination
- BGP always propagates the best path to the neighbors
- Different prefix attributes are used to determine best path, like weight, next-hop, as-path, local-pref etc.
- Setting peer to loopback address can force BGP to install ECMP route (for load balancing).



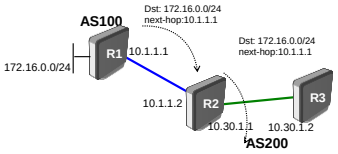

## Best path selection

- Next-hop validation
- Highest WEIGHT (default 0)
- Highest LOCAL-PREF (default 100)
- Shortest AS-PATH
- Locally originated path (aggregate, BGP network)
- Lowest origin type (IGP,EGP,Incomplete)
- Lowest MED (default 0)
- Prefer eBGP over iBGP
- Prefer the route with lowest router ID or ORIGINATOR_ID
- Shortest route reflection cluster (default 0)
- Prefer the path that comes from the lowest neighbor address




## Nexthop

- IP address that is used to reach a certain destination
- For eBGP nexthop is neighbor's IP address
- eBGP advertised nexthop is carried into iBGP.



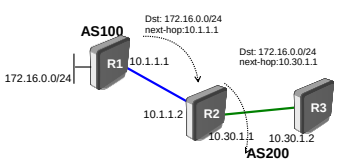




## Nexthop self

Force BGP to use specific IP as a nexthop

```
# config on R2
/routing bgp peer set peer1 nexthop-choice=force-self
```

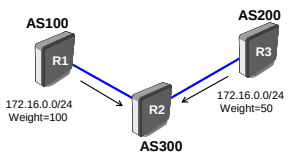






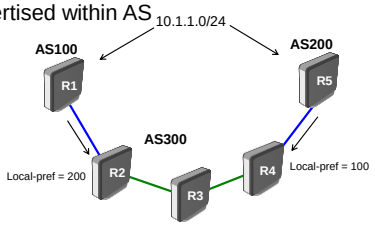
## Weight

- Weight is assigned locally to the router
- Prefix without assigned weight have default value of 0
- Route with higher weight is preferred



## Local Preference

- Indicates which path has preference to exit AS
- Path with higher Local Pref is preferred (default: 100)
- Advertised within AS

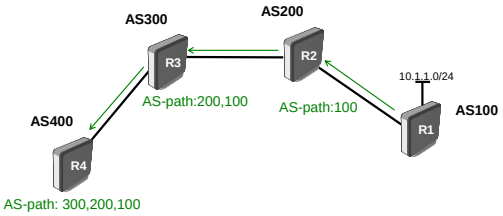






## AS Path

- List of AS numbers that an update has traversed.

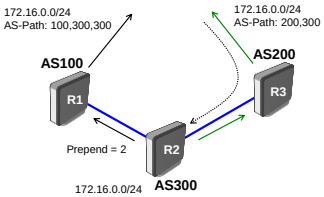






## AS-Path Prepend

AS-Path manipulations can be used to influence best path selection on upstream routers.







## Origin

- Information of route origin:
  - IGP – interior or originating AS route.
  - EGP – route learned via Exterior Gateway protocol
  - Incomplete – origin is unknown, occurs when route is redistributed into BGP.

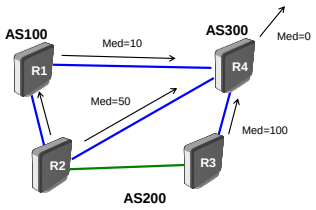



## MED

- Multi Exit Discriminator or Metric – hint to external neighbor about path preference into an AS
- Lower metric is preferred (Default: 0)
- Exchanged between AS and used to make decision inside that AS, not passed to third AS.
- Ignored if received from different ASs



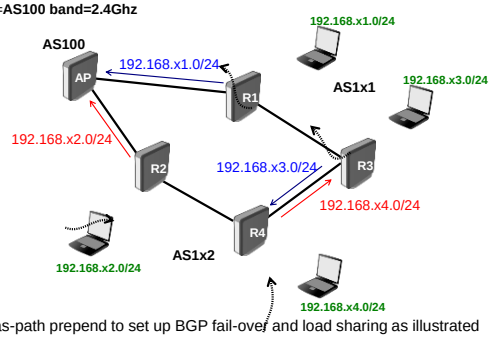

## MED Example




R1, R2 and R3 advertises the same network to R4 with different med values. R4 only compares MEDs coming from R2 and R3, MED coming from R1 is ignored (other attributes are used to select best path).

## BGP Lab V

**X** – group number
AP SSID=**AS100 band=2.4Ghz**




Use as-path prepend to set up BGP fail-over and load sharing as illustrated



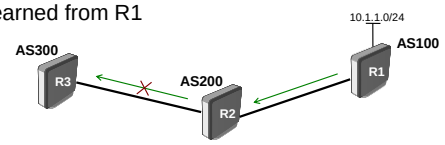

## Community

- Attribute that groups destinations
- Filters can be easily applied to whole group
- Default groups:
  - No-export – do not advertise to eBGP peer
  - No-advertise – do not advertise to any peer
  - Internet – advertise to Internet community
  - Local-as – do not send outside local AS (in non-confederation network the same as no-export)




## Community Example

Assume that you don't want R2 to propagate routes learned from R1




```
# config on R1

/routing filter add chain=bgp-out action=passthrough \
   set-bgp-communities=no-export
```



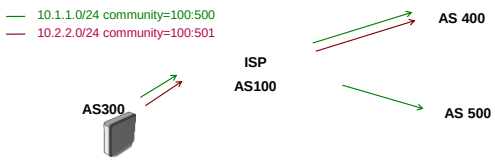

## Community cont.

- 32-bit value written in format “xx:yy”
- Gives customer more policy control
- Simplifies upstream configuration
- Can be used by ISPs for:
  - AS prepending options
  - Geographic restrictions
  - Blackholing, etc.
- Check Internet Routing Registry (IRR)




## Community Example cont.

- AS 100 defined public communities
  - 100:500 – advertise to all peers
  - 100:501 – advertise to AS 400







## Community Example cont.

```
# AS300 router config
/routing bgp peer set toAS100 out-filter=bgp-out-as100

/routing filter
 add prefix=10.1.1.0/24 action=accept\
   chain=bgp-out-as100 set-bgp-communities=100:500
 add prefix=10.2.2.0/24 action=accept\
   chain=bgp-out-as100 set-bgp-communities=100:501
```

```
# AS100 router config
/routing bgp peer set toAS500 out-filter=bgp-out-as500

/routing filter
 add bgp-communities=100:501 action=discard\
   chain=bgp-out-as500
```

## ISP example

```
aut-num:      AS2588
as-name:      LatnetServiss-AS
descr:        LATNET ISP
member-of:    AS-LATVIA
remarks:      +-------------------------------------------------
remarks:      |
remarks:      |     x=0  Announce as is
remarks:      |     x=1  Prepend +1
remarks:      |     x=2  Prepend +2
remarks:      |     x=3  Prepend +3
remarks:      |     x=4  Prepend +4
remarks:      |     x=5  Prepend +5
remarks:      |
remarks:      |     2588:400    Latvian Nets
remarks:      |     2588:500    Announce to LIX (Latvian Internet Exchange)
remarks:      |     2588:666    Don't announce (blackhole)
remarks:      |     2588:70x    Announce to uplinks with $x prepend
remarks:      |     2588:900    Recieved from LIX (Latvian Internet Exchange)
remarks:      |
remarks:      |   For more information please use the email address
remarks:      |            iproute (at) latnet (dot) lv
remarks:      +-------------------------------------------------
```




## Extended Communities

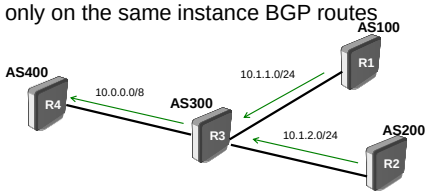
- Used to carry additional fields in L2VPN and VPNv4 setups
- Some additional fields carried:
  - Route Targets
  - Site of Origin
  - Control flags
  - MTU
  - Encapsulation flags




## Aggregation

Summarization of more specific routes into supernet. Can be used to hide topology.

Works only on the same instance BGP routes




```
# config on R3
/routing bgp aggregate add instance=default summary-only=yes \
 prefix=10.0.0.0/8  action=passthrough inherit-attributes=no
```




## BGP Route Reflector

- Re-advertises iBGP routes to avoid full mesh
- Reduces communication message count
- Minimizes amount of data per message:
  - Only best path is reflected





## Route Reflector Configuration

- RR is configured by enabling client to client reflection:

```
/routing bgp instance
set default client-to-client-reflection=yes
/routing bgp peer
add route-reflect=yes remote-peer=x.x.x.x ...
```

- Route-reflect should be enabled only on route reflector router
- RouterOS **can not** be configured as **pure** route reflector



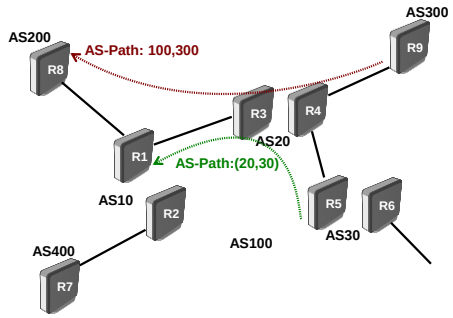

## BGP Confederation

- Divides AS into multiple ASs
- To outside world confederation appears as single AS
- Each AS must be fully meshed iBGP (or route reflectors)
- EBGP between confederation ASs exchange routing like iBGP
- AS-Path inside confederation is in scopes:
  - as-path=(30,20)

```
# confederation setup

/routing bgp instance set default confederation=100 \
  confederation-peers=20,30
```

## BGP Confederation

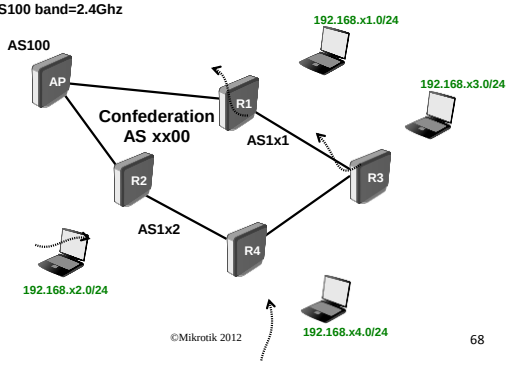






## Lab VI: Confederation

**X** – group number
AP SSID=**AS100 band=2.4Ghz**







## Confederation AS-Path

```
[admin@R1] /ip route> print detail

Flags: X - disabled, A - active, D - dynamic,
C - connect, S - static, r - rip, b - bgp, o - ospf, m - mme,
B - blackhole, U - unreachable, P - prohibit
...
 8 ADb  dst-address=192.168.12.0/24 gateway=192.168.1.10
        gateway-status=192.168.1.10 recursive via 192.168.1.2
        distance=200 scope=40 target-scope=30 bgp-as-path="(112)"
        bgp-local-pref=100 bgp-origin=igp received-from=peer2
```




## MultiProtocol BGP

- BGP packet format is designed for Ipv4
- Address family attribute was created to carry new type of addresses.
- RouterOS supported address families:
  - IPv6
  - L2VPN
  - VPN4
  - Cisco style L2VPN




## BGP Instances

- Each BGP instance runs its own BGP selection algorithm
  - Routes between instances are elected by other means (like distance)
- Routes from one instance are not redistributed automatically to another instance
  - Needs:
    **/routing bgp instance**
    set <id> redistribute-other-bgp=yes
- BGP attributes are inherited from another instance



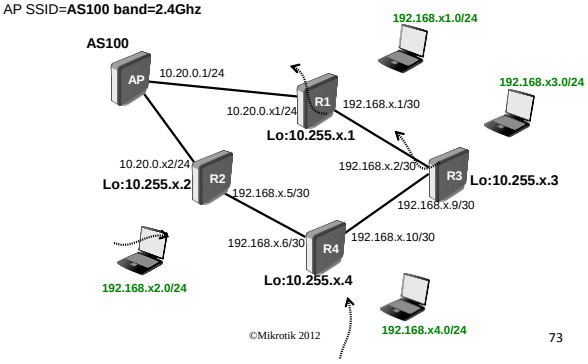

## Multi-protocol Label Switching (MPLS)

LDP, VPNs (layer2,layer3), TE

## MPLS Lab Setup

**X** – group number

AP SSID=**AS100 band=2.4Ghz**








## MPLS Lab Setup

- Reset router's configuration
- Set up configuration as illustrated
- Set up loopback addresses and run OSPF on all links
- Add loopback addresses to OSPF networks





## MPLS Basics

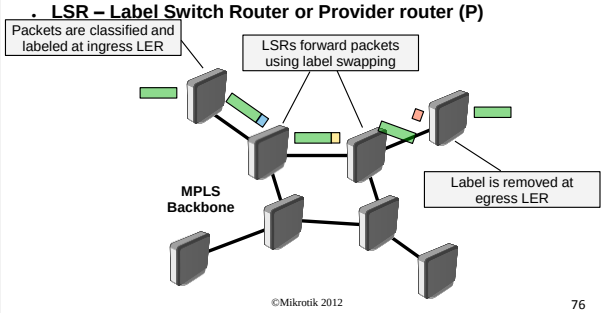
- Technology used to forward packets, based on short labels
- Initial goal: more efficient forwarding than IP routing (similar to ATM switching)
- Serves as foundation for some "Advanced Services":
  - Layer3 VPNs
  - Any Transport over MPLS (AtoM), Layer2 VPNs
  - MPLS Traffic Engineering
  - Guaranteed bandwidth services





## MPLS Basics

- **LER – Label Edge Router or Provider Edge router (PE)**
- **LSR – Label Switch Router or Provider router (P)**

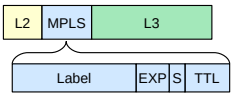







## MPLS Basics

- **Also called 2.5 layer protocol**
- **Shim header (32 bit) placed between OSI Layer2 and Layer3:**
  - Label (20 bits)
  - EXP (3 bits) - CoS
  - End of stack flag(1 bit) – whether current label is the last in the stack
  - TTL (8 bits)








## MPLS Basics

- More than one label is allowed.
- Labels are grouped into label stack
- LSRs always use the top label of the stack
- Several Label distribution methods exist:
  - Static Label mapping
  - LDP – maps unicast IP destination into label
  - BGP – external labels (VPN)
  - RSVP,CR-LDP – used for traffic engineering and resource reservation

## Static Label Mapping

- RouterOS allows to add static local and remote bindings for every destination.
- MPLS dynamic label range must be adjusted to free labels for static bindings.

```
/mpls set dynamic-label-range=100-1048575
/mpls local-bindings
/mpls remote-bindings
/mpls forwarding-table
```




## Static Label Mapping


**Local:**

| DST | LABEL |
|---|---|
| 1.1.1.1 | impl-null |
| 2.2.2.2 | 22 |
| 3.3.3.3 | 23 |

| DST | LABEL |
|---|---|
| 1.1.1.1 | 21 |
| 2.2.2.2 | impl-null |
| 3.3.3.3 | 23 |

| DST | LABEL |
|---|---|
| 1.1.1.1 | 21 |
| 2.2.2.2 | 22 |
| 3.3.3.3 | impl-null |

**Remote:**

| DST | HOP | LABEL |
|---|---|---|
| 2.2.2.2 | R2 | impl-null |
| 3.3.3.3 | R2 | 23 |

| DST | HOP | LABEL |
|---|---|---|
| 1.1.1.1 | R1 | impl-null |
| 3.3.3.3 | R3 | impl-null |

| DST | HOP | LABEL |
|---|---|---|
| 2.2.2.2 | R2 | impl-null |
| 1.1.1.1 | R2 | 21 |

**Fwd:**

| IN | OUT | DST |
|---|---|---|
| 22 | | 2.2.2.2 |
| 23 | 23 | 3.3.3.3 |

| IN | OUT | DST |
|---|---|---|
| 21 | | 1.1.1.1 |
| 23 | | 3.3.3.3 |

| IN | OUT | DST |
|---|---|---|
| 21 | 21 | 1.1.1.1 |
| 22 | | 2.2.2.2 |




## Test with traceroute

```
[admin@R1] /mpls forwarding-table> print
Flags: L - ldp, V - vpls, T - traffic-eng
 #    IN-LABEL  OUT-LABELS DESTINATION     INTERFACE  NEXTHOP
 0    expl-null
 ...
 4 L 23        23         3.3.3.3/32      ether1     10.20.0.11
[admin@R1] >/tool traceroute 3.3.3.3 src-address=1.1.1.1
 # ADDRESS              RT1   RT2   RT3   STATUS
 1 10.20.0.11           2ms   1ms   2ms   <MPLS:L=23,E=0>
 2 3.3.3.3              1ms   1ms   2ms
```




## Static Mapping LAB

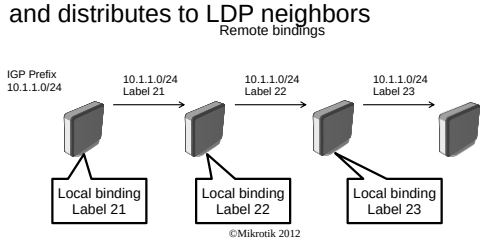
- Create static label bindings for loopback addresses
- Since ECMP is not used in label binding, choose only first gateway
- Test if labels are set with traceroute:

  /tool traceroute 10.255.1.1 src-address=10.255.1.3




## LDP

- Stands for Label Distribution Protocol
- Relies on routing information provided by IGP – creates a local label binding to each IP prefix and distributes to LDP neighbors

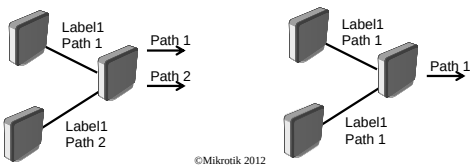






## Label space

- Per interface label space – packet is forwarded based on both the incoming interface and the label
- Per platform label space – label is not unique per interface



## Distribution Modes

- Downstream-on-Demand (DoD) – each LSR requests its next-hop label binding. (Not yet implemented)
- Unsolicited Downstream (UD) – LSR distributes a binding all adjacent LSRs even if LSRs are requesting a label.




## Well known numbers

- LDP Hello messages – UDP port 646
- LDP transport session establishment – TCP port 646
- Hellos are sent to "all routers in this subnet" multicast address (224.0.0.2)




## Configuring LDP

- Can be configured in "`/mpls ldp`" menu

```
/mpls ldp set enabled=yes transport-address=x.x.x.x \
   lsr-id=x.x.x.x
/mpls ldp interface add interface=ether1
```

- Setting transport address ensures proper penultimate hop popping behavior




## LDP Lab

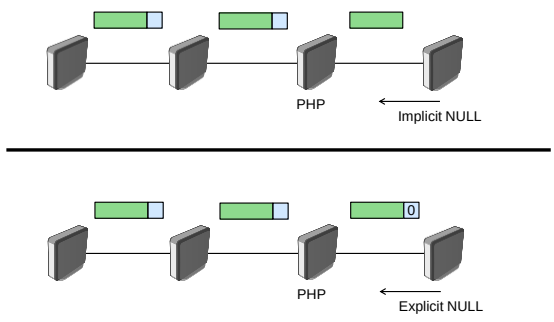
- Remove all static mapping from previous lab
- Enable LDP and set lsr-id and transport address the same as loopback address
- Add LDP interfaces connecting neighbor routers
- Verify if LDP neighbors are created
  `/mpls ldp neighbor print`
- Check MPLS forwarding-table
  `/mpls forwarding-table print`




## Reserved Labels

- Labels from 0 to 15 are reserved, but only 4 are used at this point:
  - 0 – explicit NULL
  - 1 – router alert
  - 2 – Ipv6 explicit NULL
  - 3 – implicit NULL



## Penultimate Hop Popping

- Router is egress point for network that is directly connected to it, next hop for traffic is not MPLS router
- Advertised with “implicit null” label
- Penultimate hop popping ensures that routers do not have to do unnecessary label lookup when it is known in advance that router will have to route packet



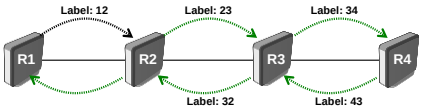

## Explicit NULL

- If configured, penultimate LSR forwards packet with NULL label, instead of popping stack.
- Useful to preserve QoS
- Not required if stack contains at least two labels (inner label can still carry QoS value)
- Implicit NULL is used by default




## MPLS Traceroute

- ICMP error messages are switched further along LSP
- It will give false increase in latency for that hop



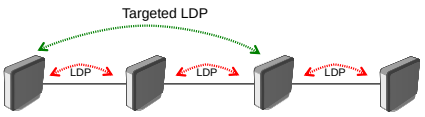




## Targeted LDP Sessions

- In some cases it is necessary to set up targeted LDP session (session between not directy connected LSRs)
- Configuration:

```
/mpls ldp neighbor add transport=<remote_ip> \
    send-targeted=yes
```







## Label Binding Filtering

- Can be used to distribute only specified sets of labels to reduce resource usage
- Two types of binding filters:
  - Which bindings should be advertised **`/mpls ldp advertise-filter`**
  - Which bindings should be accepted **`/mpls ldp accept-filter`**
- Filters are applied only to incoming/outgoing advertisements. Any changes to filters requires ldp disable/enable

```
/mpls ldp advertise-filter add prefix=9.9.9.0/24 advertise=yes
/mpls ldp advertise-filter add prefix=0.0.0.0/0 advertise=no
```




## Label Binding LAB

- Set up label binding filters so that only bindings to loopback addresses from your group are sent and received.
- Check forwarding table to make sure filters worked
- Check if packets are label switched or L3 forwarded with traceroute

Layer3 VPN

VRF




## VRF

- Virtual Routing and Forwarding
- Based on policy routing
- Functionality of completely independent routing tables on one router.
- Multiple VRFs solves the problem of overlapping customer IP prefixes
- When nexthop resolving fails it is not resolved in main table (compared to policy routing)




## Route Leaking

- Route leaking is route exchange between separate VRFs
- Static Inter-VRF route:
  - Explicitly specified routing table (works with “main”)

```
/ip route
add gateway=10.3.0.1@main routing-mark=vrf1
```

  - Explicitly specify interface

```
/ip route
add dst-address=5.5.5.0/24 gateway=10.3.0.1%ether2 \
routing-mark=main
```




## VRF and Router Management

- Any router management is not possible from vrf side (winbox, telnet, ssh ...)
- Ping and traceroute tools are updated to support VRFs
- OSPF and BGP can be used as CE-PE protocol

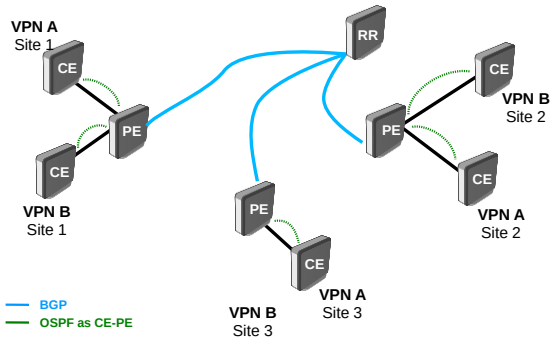



## BGP/MPLS IP VPN

- Works in Layer3 unlike BGP based VPLS.
- Also called L3VPN
- Multiprotocol BGP is used to distribute routes between VRFs even in router itself.
- Provider network MUST be MPLS enabled




## L3VPN



## Route Distinguisher

- Route distinguisher (RD) is used to make IPv4 prefixes unique
- RD+IPv4 prefix=**vpnv4** prefix
- Format
  - IP:num
  - ASn:num
- Note: Some complex scenarios may require more than one RD by VPN

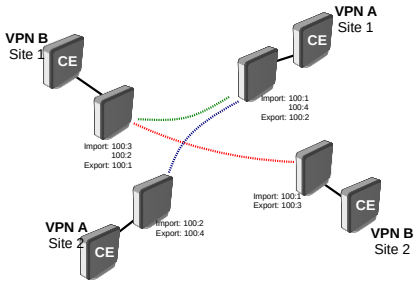



## Route Target

- Route Targets (RTs) were introduced for the ability to have interconnection between the sites of different companies, called **extranet** VPNs.
- Route Targets are BGP extended community to specify what vpnv4 prefixes will be imported into VRF table.
- Exporting RT - vpnv4 receives an additional BGP extended community
- Importing RT – received vpnv4 route is checked for a matching RT




## Route Target







## Configuring L3VPN

- Create VRF instance

```
/ip route vrf
  add routing-mark=vrf1
  route-distinguisher=100:1
  export-route-targets=100:1
  import-route-targets=100:1
```

- Configure BGP to use VRF and vpnv4 address family

```
/routing bgp instance vrf
  add instance=default routing-mark=vrf1 \
  redistribute-connected=yes
/routing bgp peer
  add address-families=vpnv4 update-source=lo ...
```

- Results

```
/routing bgp vpn vpnv4 route print
```

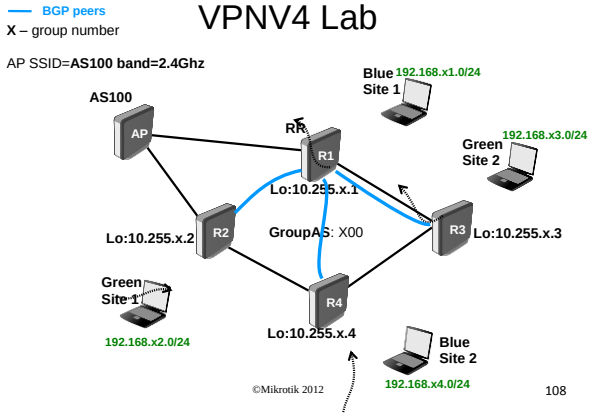



## VPNV4 Lab

- Choose Route Reflector and set up iBGP (group AS: X00)
- Set up VPNV4 BGP
- Create VRF with interface where your laptop is connected
- Route Distinguisher and export RT: X00:Y
- Set up proper import route targets, so that only Green sites and Blue sites exchange routes (see next slide)
- Set up route leaking to access internet from VRF




## VPNV4 Lab



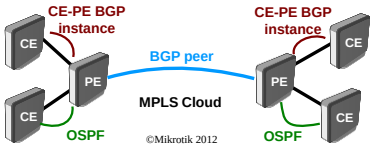
## OSPF and eBGP as CE-PE

- Distributes routes between CE and PE router's VRF
- On PE router specify which VRF to use

```
/routing ospf instance
set default routing-table=vrf1 redistribute-bgp=as-type-1
```

- New instance to use eBGP as CE-PE

```
/routing bgp instance
add name=ebgp as=100 routing-table=vrf1
```







Layer 2 VPN

LDP Based VPLS

BGP Based VPLS

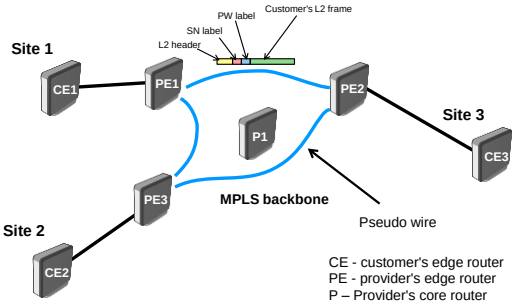



## LDP based VPLS

- Also called L2VPN or EoMPLS
- Glues together individual LANs across MPLS
- Uses LDP to negotiate VPLS tunnels
- Pseudowire demultiplexor field (PW label) is used to identify VPLS tunnel
- Pseudowire has MAC learning, flooding and forwarding functions




## LDP based VPLS







## Configuring VPLS

- Add VPLS tunnel termination points:
  **/interface vpls**
  add **remote-peer**=x.x.x.x **vpls-id**=x:x
- Dynamic targeted LDP neighbor is added
- VPLS tunnel ID must be unique for every VPLS
- Related VPLS tunnel information can be viewed by **/interface vpls monitor** command
- Bridge VPLS interface with local one to provide transparent connectivity



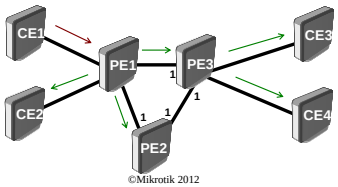

## Configuring VPLS

- Add VPLS tunnel termination points:
  **/interface vpls**
  add **remote-peer**=x.x.x.x **vpls-id**=x:x
- Dynamic targeted LDP neighbor is added
- VPLS tunnel ID must be unique for every VPLS
- Related VPLS tunnel information can be viewed by **/interface vpls monitor** command
- Bridge VPLS interface with local one to provide transparent connectivity

## Split Horizon

- Forward Ethernet frame coming from PE to connected CEs
- Packets are not forwarded to interfaces with the same horizon value
- Horizon value is set in bridge port configuration

```
/interface bridge port
   add bridge=vpn interface=vpls1 horizon=1
```







## LDP VPLS Lab

- Create VPLS tunnels between all routers from the group (VPLS ID x:x)
- Bridge VPLS interfaces with local interface on your router.
- VPN network is 192.168.x0.0/24 where:
  - x - group number
- Set up Split horizon to avoid loops
- Test connectivity between laptops in your group




## LDP VPLS Lab

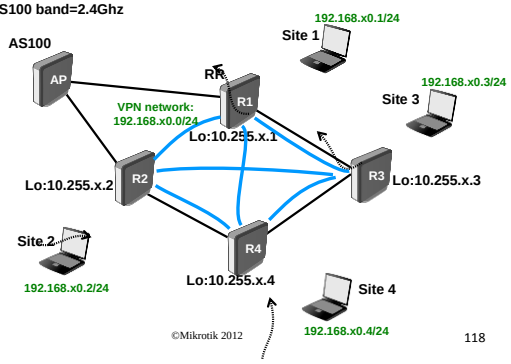
- Create VPLS tunnels between all routers from the group (VPLS ID x:x)
- Bridge VPLS interfaces with local interface on your router.
- VPN network is 192.168.x0.0/24 where:
  - x - group number
- Set up Split horizon to avoid loops
- Test connectivity between laptops in your group




## LDP VPLS Lab

VPLS tunnel
**X** – group number

AP SSID=**AS100 band=2.4Ghz**







```
[admin@R4] /mpls ldp neighbor> print
Flags: X - disabled, D - dynamic, O - operational, T - sending-
targeted-hello, V - vpls
 #      TRANSPORT  LOCAL-TRANSPORT PEER  SEND-TARGETED ADDRESSES
 0 DOTV 10.255.0.3 10.255.0.4  10.255.0.3:0  no     10.255.0.3
                                                    192.168.1.2

 1 DOTV 10.255.0.2 10.255.0.4  10.255.0.2:0  no     10.20.0.12
10.255.0.2

 2 DOTV 10.255.0.1 10.255.0.4  10.255.0.1:0  yes    10.20.0.11
                                                    10.255.0.1

[admin@R4] /interface vpls> monitor 0
       remote-label: 40
        local-label: 28
      remote-status:
          transport: 10.255.0.1/32
  transport-nexthop: 192.168.1.9
     imposed-labels: 22,40
```

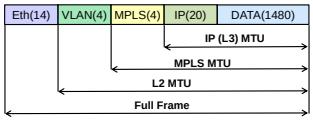



## LDP based VPN drawbacks

- Scalability issues due to static nature
- Requirement to maintain full mesh of LDP tunnels
- Configuration adjustment on all routers forming VPLS

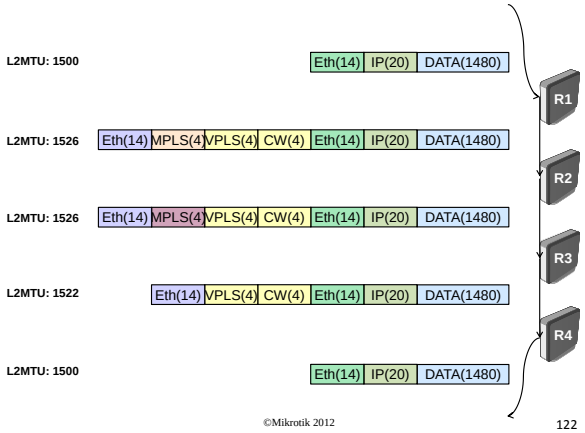
## L2/MPLS MTU Importance

- MPLS MTU = IP MTU (L3) + MPLS headers
- MPLS MTU is adjustable from "**/mpls interface"** menu
- If MTU is too large and next header is IP
  - Then generate "ICMP Need Fragment error"
  - Else silently discard packet











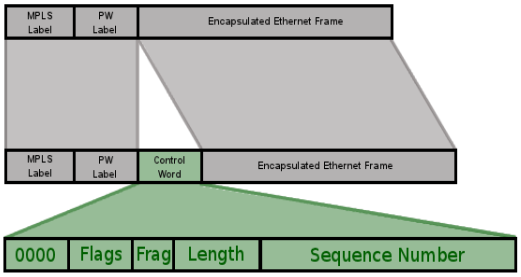


## VPLS Control Word

- 4-byte Control Word (CW) is used for packet fragmentation and reassembly inside VPLS tunnel
- Optional CW is added between PW label and packet payload
- CW can be turned off for compatibility with other vendors (some Cisco BGP based VPLS)




**VPLS Encapsulated Packet with and without Control Word**







## BGP Based VPLS

- BGP VPLS functionality
  - **Autodiscovery** – no need to configure each VPLS router
  - **Signaling** – labels for VPLS tunnels distributed in BGP updates.
- No need for targeted LDP sessions
- No scalability issues
- No significant advantages over LDP in case of full mesh BGP.




## BGP Based VPLS configuration

- Configure BGP instance
- Enable **l2vpn** in BGP peer's **address-families** to use BGP multi protocol capability
- Use loopback address as BGP peers address by specifying **update-source**, in order for penultimate hop popping to work properly.

```
/routing bgp peer
add remote address=1.1.1.1 remote-as=100 update-source=lo
address-families=l2vpn
```

## BGP Based VPLS configuration

- Configure VPN bridge
- Configure BGP signaled VPLS interface

```
/interface vpls bgp-vpls
add bridge=<bridge> bridge-horizon=1 site-id=1 \
route-distinguisher=1:1 import-route-targer=1:1 \
export-route-target=1:1
```

- Dynamic VPLS tunnel gets created and added to bridge ports
  - **route-distinguisher** – value that gets attached to VPLS NLRI to distinguish advertisements, value should be unique for each VPLS
  - **site-id** – unique setting among members of particular VPLS




## BGP based VPLS Lab

- Choose which one of routers will be Route reflector (for example R1)
- Set BGP peering only between RR
- Replace all statically created VPLS with BGP VPLS
- Set import/export route targets the same as route distinguisher.

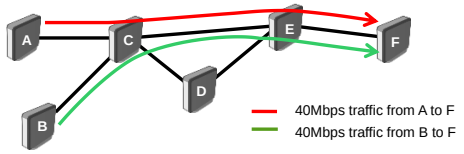



## Traffic Engineering




## IP Routing Limitation

- After two IP traffic flows for the same destination are merged, it is impossible to split them and reroute over different paths
- Overloaded link from Router C to Router E

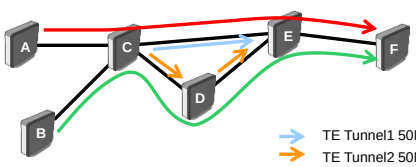






## Traffic Engineering

- TE solves the problem
- Can be used to steer traffic to less utilized links







## Traffic Engineering

- Expands the capabilities of L2 ATM and Frame relay networks
- Constraint based routing - path for the traffic flow is shortest path that meets resource requirements (constraints)
- Eliminates the need of overplayed L2 mesh.

## How it works

- TE establishes/maintains the tunnel using RSVP (Resource Reservation Protocol)
- Tunnel path at any point is determined based on network resources and tunnel requirements
- Available resources are flooded via OSPF
- Tunnel paths are calculated at the tunnel head based on a fit between required and available resources (constraint-based routing)
- RSVP TE tunnels are unidirectional




## TE Tunnel Path Options

- Tunnel path is routed based on routing table
  Tunnel path: use-cspf=no and empty hops
- Statically configured explicit path
  Tunnel path: use-cspf=no hops=<explicit hop config>
- Constrained Shortest Path First (CSPF) – head end router calculates path to tail end using knowledge of network state. Needs assistance form IGP.
  Tunnel path: use-cspf=yes, empty hops or explicitly configured hops




## How it works

- Tunnel head end appears as interface
- Auto TE works within the range of one area
- Traffic can be forwarded automatically to TE if
  - Remote endpoint of pseudowire is the same as TE endpoint
  - BGP nexthop is tunnel endpoint ( can be turned off by setting “use-te-nexthop=no”)




## TE configuration

- Set OSPF to use TE and configure TE on all interfaces participating in TE tunnel

```
/routing ospf set mpls-te-area=backbone
mpls-te-router-id=loopback
/mpls traffic-eng interface
add interface=ether1 bandwidth=50Mbps
```

- Configure TE tunnel itself

```
/mpls traffic-eng tunnel-path
add use-cspf=no name=rt
/interface traffic-eng
add bandwidth=10Mbps primary-path=rt
from-address=10.255.1.2 to-address=10.255.1.3
```




## TE configuration

- OSPF Result (should have opaque LSAs)
- TE tunnel monitoring

```
[admin@R2] /interface traffic-eng> monitor 0
                tunnel-id: 3
    primary-path-state: established
           primary-path: rt
  secondary-path-state: not-necessary
            active-path: rt
          active-lspid: 1
          active-label: 124
       recorded-route: 192.168.1.1[124],192.168.1.2[0]
    reserved-bandwidth: 10.0Mbps

[admin@R2] /interface vpls> monitor 0
       remote-label: 114
        local-label: 113
      remote-status:
           transport: traffic-eng1
  transport-nexthop: 10.20.0.11
     imposed-labels: 124,114
```




## TE configuration

- TE tunnel path and reservation state

```
[admin@R2] /mpls traffic-eng path-state> print
Flags: L - locally-originated, E - egress, F - forwarding, P - sending-
path, R - sending-resv
 #      SRC                 DST             BANDWIDTH OUT.. OUT-NEXT-HOP
 0 LFP  10.255.1.2:1        10.255.1.3:3  10.0Mbps R2_R4 10.20.0.11
[admin@R2] /mpls traffic-eng resv-state> print
Flags: E - egress, A - active, N - non-output, S - shared
 #    SRC                 DST                 BANDWIDTH LABEL  INT...
 0 AS 10.255.1.2:1        10.255.1.3:3        10.0Mbps  124    R2_R4

[admin@R2] /mpls traffic-eng interface> print
Flags: X - disabled, I - invalid
 #   INTERFACE                          BANDWIDTH  TE-METRIC REMAINING-BW
 0   R2_R1                                 50Mbps          1     50.0Mbps
 1   R2_R4                                 50Mbps          1     40.0Mbps
```

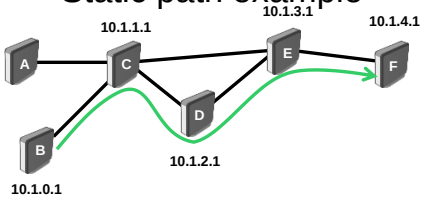
## Static Path

- Static path is established by setting strict or loose hops:
  - Strict - defines that there must not be any other hops between previous hop and "strict" hop (fully specified path)
  - Loose - there are acceptable other hops between previous hop and defined hop (not fully specified path).

```
/mpls traffic-eng tunnel-path
add use-cspf=no \
hops=10.1.1.1:strict,10.1.3.1:loose,10.1.4.1:strict
```




## Static path example




```
10.1.2.1:loose

10.1.1.1:strict,10.1.2.1:strict, 10.1.4.1:loose

10.1.1.1:strict,10.1.2.1:strict,10.1.3.1:strict,10.1.4.1:strict
```




## TE Lab I

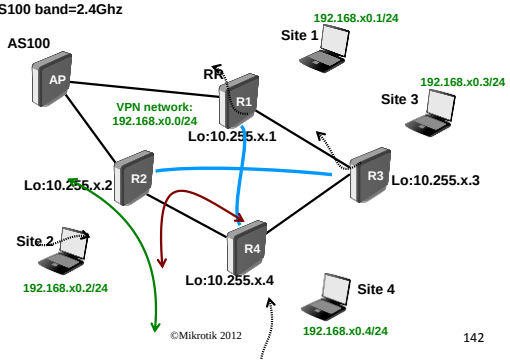
- Set up TE tunnels so that VPLS tunnels uses following switching paths:
  - VPLS: R1<->R4; TE Path: R1-R3-R4 primary
  - VPLS: R2<->R3: TE Path: R2-R4-R3 primary
- Experiment with different TE path types.




## TE Lab I

VPLS tunnel
**X** – group number

AP SSID=**AS100 band=2.4Ghz**







## Secondary TE Tunnel Path

- TE does not switch paths automatically to secondary, tunnel must be reoptimized:
  - Manually ("optimize" command);
  - Automatically (at configured"reoptimize-interval")
- TE tries to switch back to primary every minute (can be changed by "primary-retry-interval")
- Switching paths may take some time, depends on: OSPF timeouts, routing table updates, TE timeout settings.




## Auto Bandwidth

- By default TE tunnels do not apply rate limitations, "bandwidth" settings are only for reservation accounting
- To make tunnels more flexible two features were added:
  - **"bandwidth-limit"** – hard rate limit allowed to enter the tunnel, limit is percent of tunnel bandwidth.
  - **Auto bandwidth adjustment** – measures average rate during *"auto-bandwidth-avg-interval"*, tunnel keeps highest avg rate seen during *"auto-bandwidth-update-interval"*. When update interval expires, tunnel chooses new highest rate from *"auto-bandwidth-range"*.
- Both options can be used in combination.

## TE Lab II

- Set up TE tunnels so that VPLS tunnels uses following primary and backup switching paths:
  - VPLS: R1<->R4; TE Path: R1-R3-R4 primary, R1-R2-R4 backup
  - VPLS: R2<->R3: TE Path: R2-R1-R3 primary, R2-R4-R3 backup
- Set up TE tunnel bandwidth limit (automatic and static) and test limitation with bandwidth test.

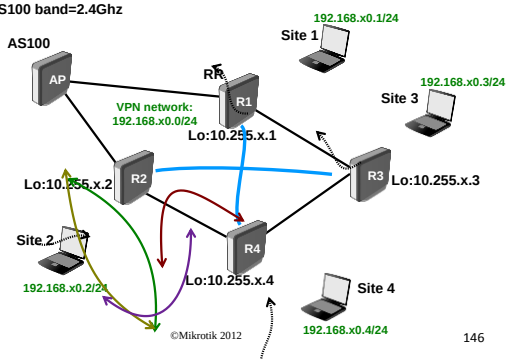



## TE Lab II

VPLS tunnel

**X** – group number

AP SSID=**AS100 band=2.4Ghz**







## Overall Summary

- MPLS improves performance
- Very easy to enable over existing core configuration
- Very easy to migrate from EoIP to VPLS
- New possibilities for ISPs to offer new services