Quality of Service

Class 5: Advanced Topics

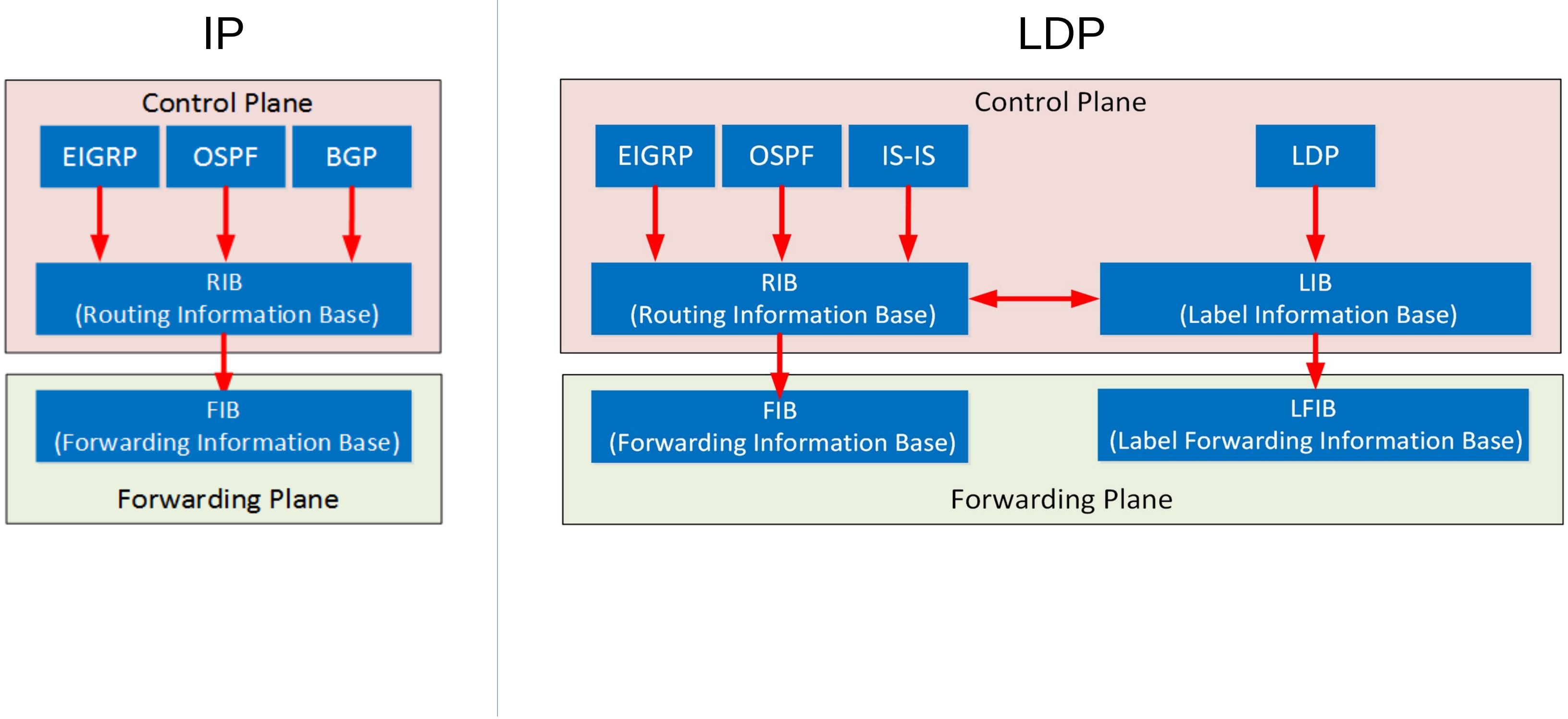
Traffic Engineering

MPLS – Label Distribution Protocol

- Label Distribution Protocol (LDP) generates and exchanges labels between routers
- It is based on Cisco’s Tag Distribution Protocol
- It is defined under RFC 5036
- MLPS-LDP is the base of all MPLS variants

MPLS-LDP

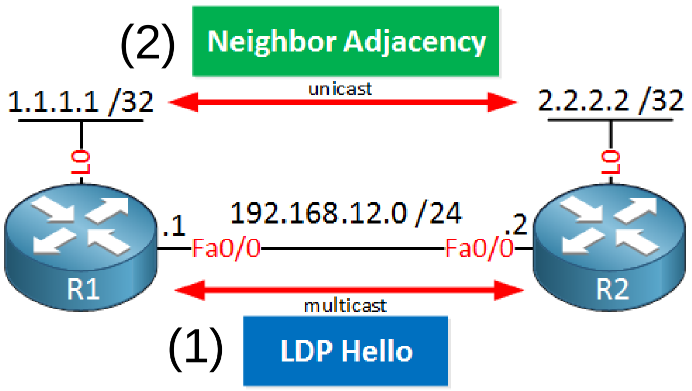
Routing Information Structure



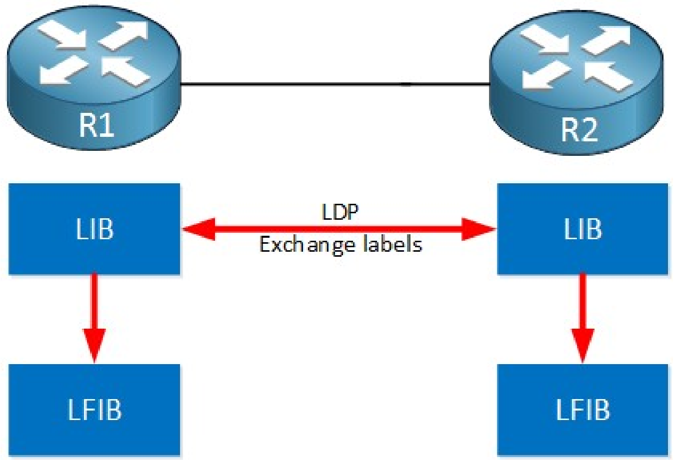
MPLS-LDP

Operation

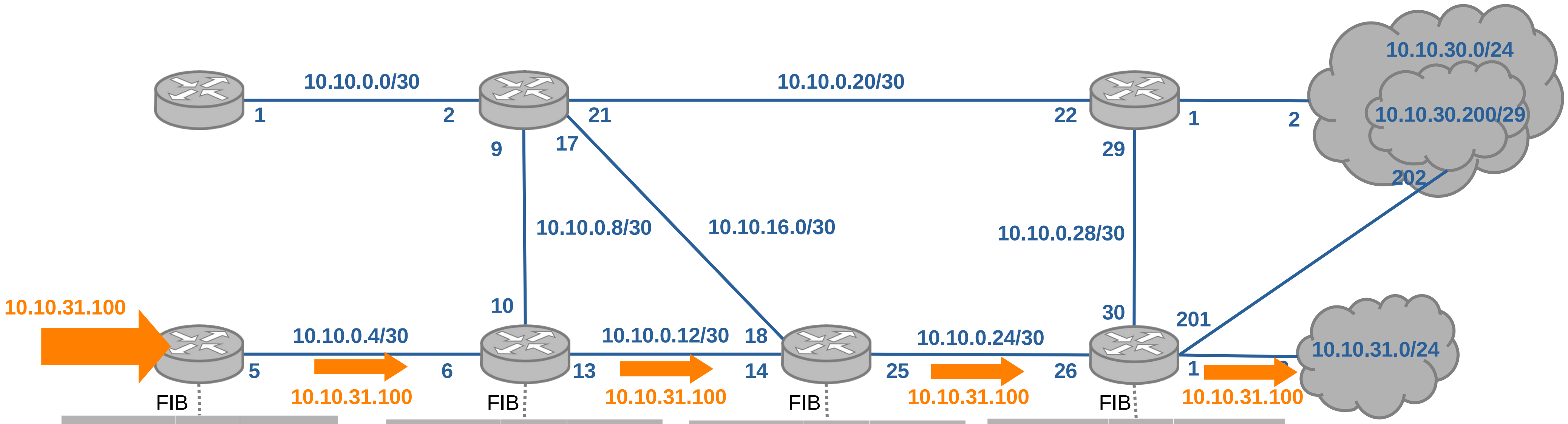
Phase 1: Neighborhood Discovery



Phase 2: Label Exchange



Classic IP Routing



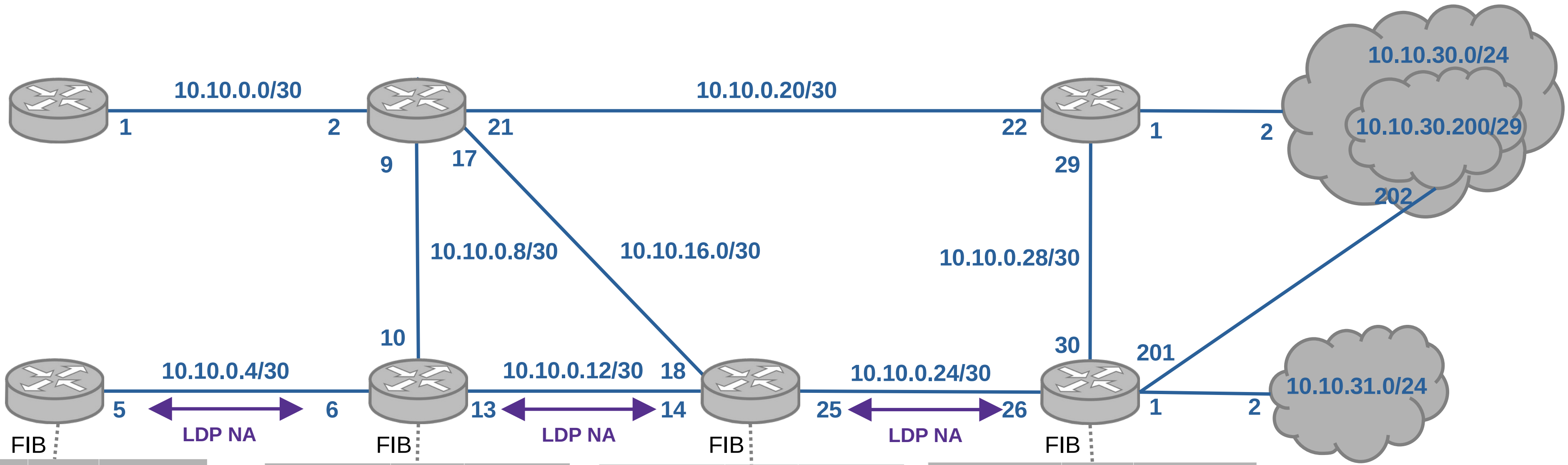
Route	Mask	Next Hop
10.10.30.200	/29	10.10.0.6
10.10.30.0	/24	10.10.0.6
10.10.31.0	/24	10.10.0.6

Route	Mask	Next Hop
10.10.30.200	/29	10.10.0.14
10.10.30.0	/24	10.10.0.9
10.10.31.0	/24	10.10.0.14

Route	Mask	Next Hop
10.10.30.200	/29	10.10.0.26
10.10.30.0	/24	10.10.0.17
10.10.31.0	/24	10.10.0.26

Route	Mask	Next Hop
10.10.30.200	/29	10.10.30.202
10.10.30.0	/24	10.10.0.29
10.10.31.0	/24	10.10.31.2

MPLS-LDP Routing



FIB

Route	Mask	Next Hop
10.10.30.200	/29	10.10.0.6
10.10.30.0	/24	10.10.0.6
10.10.31.0	/24	10.10.0.6

FIB

Route	Mask	Next Hop
10.10.30.200	/29	10.10.0.14
10.10.30.0	/24	10.10.0.9
10.10.31.0	/24	10.10.0.14

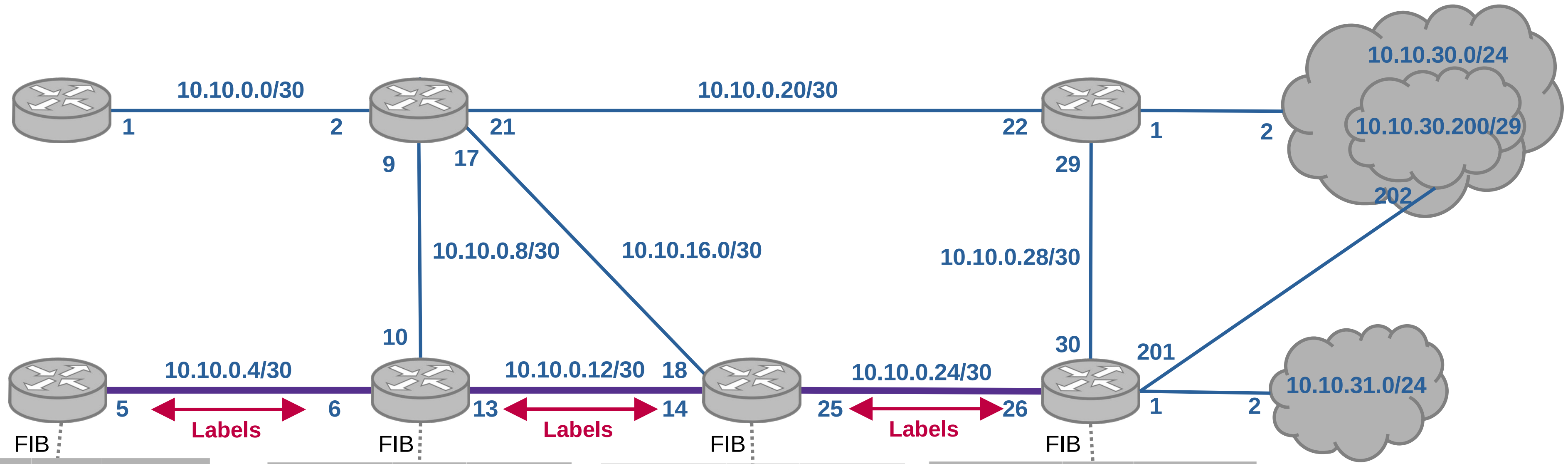
FIB

Route	Mask	Next Hop
10.10.30.200	/29	10.10.0.26
10.10.30.0	/24	10.10.0.17
10.10.31.0	/24	10.10.0.26

FIB

Route	Mask	Next Hop
10.10.30.200	/29	10.10.30.202
10.10.30.0	/24	10.10.0.29
10.10.31.0	/24	10.10.31.2

MPLS-LDP Routing



FIB

Route	Mask	Next Hop
10.10.30.200	/29	10.10.0.6
10.10.30.0	/24	10.10.0.6
10.10.31.0	/24	10.10.0.6

LIB

Route	Mask	Label
10.10.30.200	/29	2
10.10.31.0	/24	2

FIB

Route	Mask	Next Hop
10.10.30.200	/29	10.10.0.14
10.10.30.0	/24	10.10.0.9
10.10.31.0	/24	10.10.0.14

LFIB

Label In	Label Out
2	1

FIB

Route	Mask	Next Hop
10.10.30.200	/29	10.10.0.26
10.10.30.0	/24	10.10.0.17
10.10.31.0	/24	10.10.0.26

LFIB

Label In	Label Out
1	0

FIB

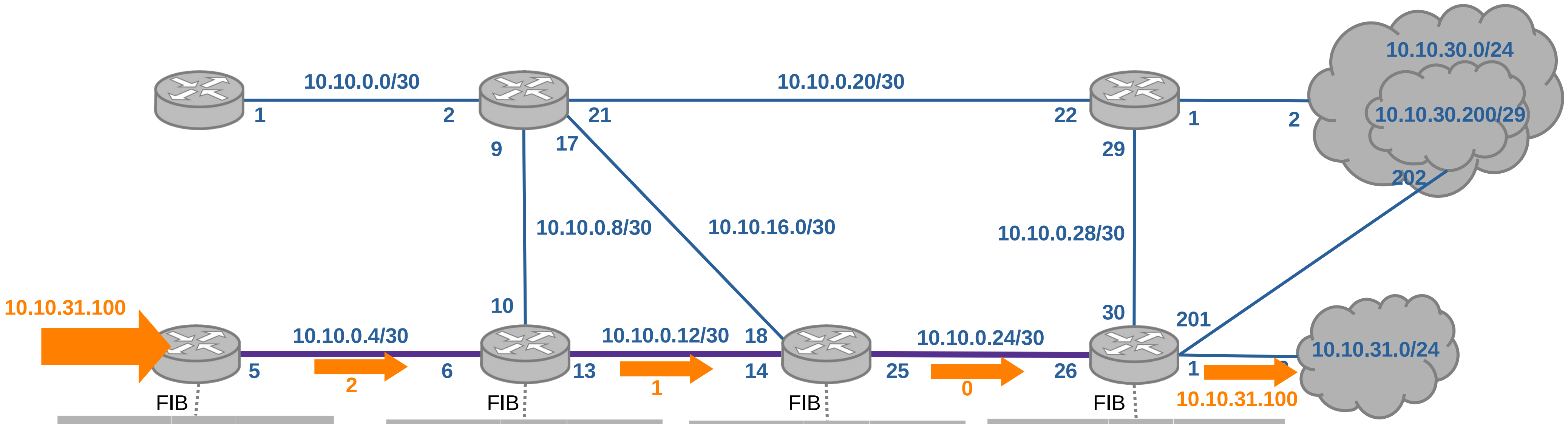
Route	Mask	Next Hop
10.10.30.200	/29	10.10.30.202
10.10.30.0	/24	10.10.0.29
10.10.31.0	/24	10.10.31.2

Edge Router for these subnets

LIB

Route	Mask	Label
10.10.30.200	/29	0
10.10.31.0	/24	1

MPLS-LDP Routing



FIB

Route	Mask	Next Hop
10.10.30.200	/29	10.10.0.6
10.10.30.0	/24	10.10.0.6
10.10.31.0	/24	10.10.0.6

LIB

Route	Mask	Label
10.10.30.200	/29	2
10.10.31.0	/24	2

FIB

Route	Mask	Next Hop
10.10.30.200	/29	10.10.0.14
10.10.30.0	/24	10.10.0.9
10.10.31.0	/24	10.10.0.14

LFIB

Label In	Label Out
2	1

FIB

Route	Mask	Next Hop
10.10.30.200	/29	10.10.0.26
10.10.30.0	/24	10.10.0.17
10.10.31.0	/24	10.10.0.26

LFIB

Label In	Label Out
1	0

FIB

Route	Mask	Next Hop
10.10.30.200	/29	10.10.30.202
10.10.30.0	/24	10.10.0.29
10.10.31.0	/24	10.10.31.2

LIB

Route	Mask	Label
10.10.30.200	/29	0
10.10.31.0	/24	1

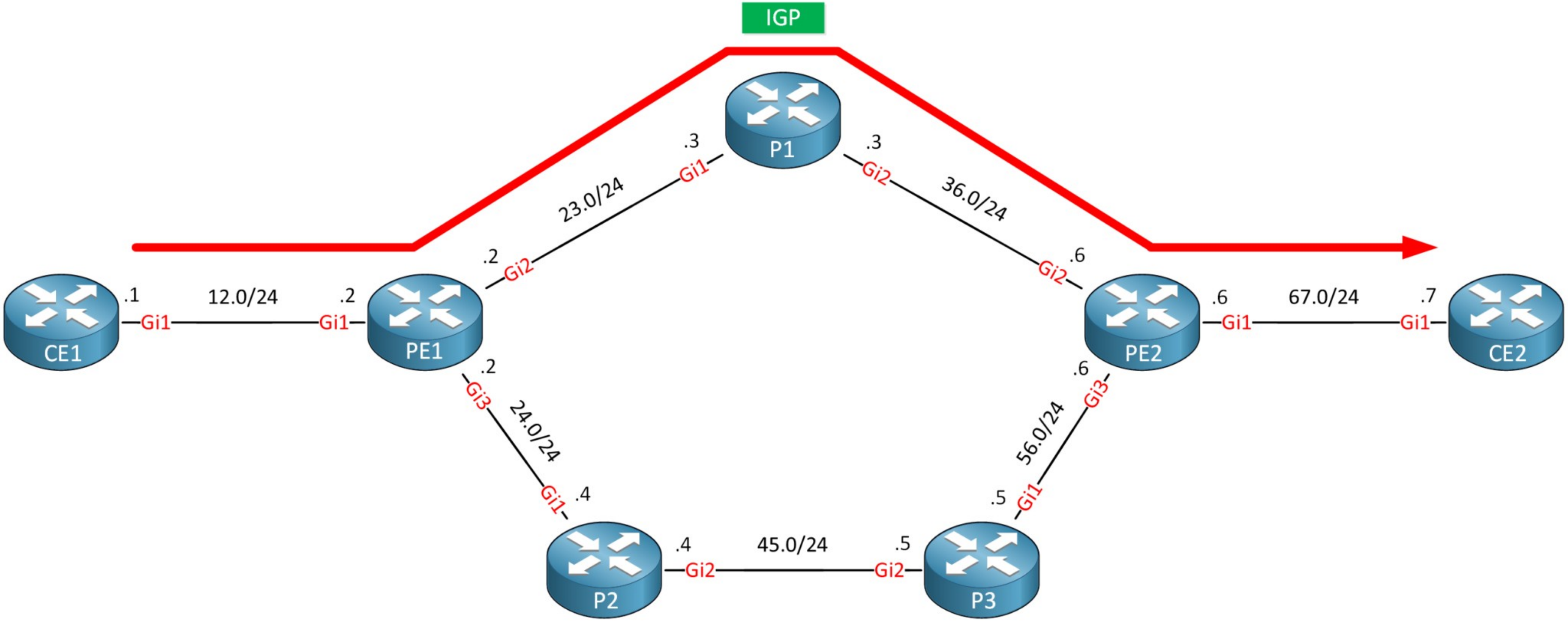
MPLS-LDP Characteristics

- Point-to-point routing (vs. End-to-end IP routing)
  - No idea of flow
- No QoS constraints
- TCP-based protocol
- Tunneling-like communication

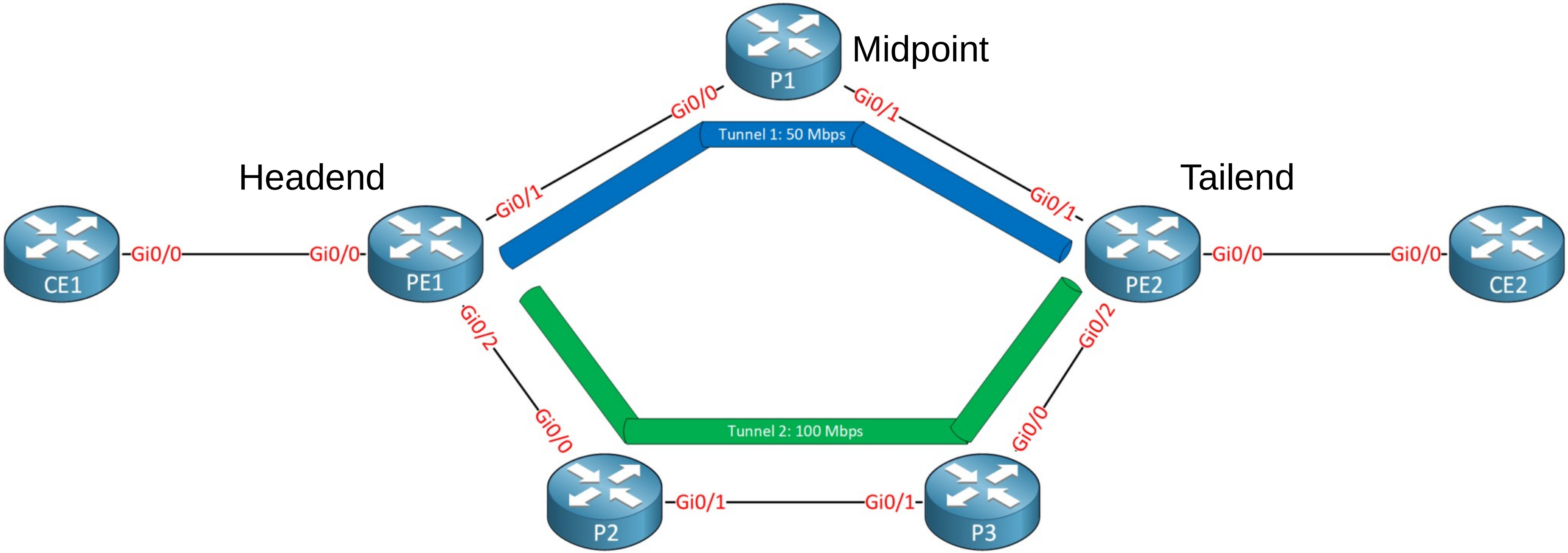
MPLS – Traffic Engineering

- MPLS Traffic Engineering (TE) is a mechanism to define traffic flows in a MPLS core network
- MPLS-TE relies on Label Switched Paths (LSPs) such as those defined in MPLS-LDP
- LSPs are unidirectional tunnels from source router to destination router
- LSPs may impose QoS requirements (e.g., throughput, delay, priority, etc.)

MPLS-TE: IGP vs. LSPs



MPLS-TE: IGP vs. LSPs



MPLS-TE Operation

Components:

1) Link Information Distribution
2) Path Calculation (CSPF)
3) Path Setup (RSVP-TE)
4) Forwarding through LSPs

MPLS-TE Operation

Components:

1) Link Information Distribution
2) Path Calculation (CSPF)
3) Path Setup (RSVP-TE)
4) Forwarding through LSPs

- Links attributes are locally collected. They include:
  - Capacity
  - Used/Available capacity
  - Affinity flags
  - Other traffic engineering indicators
- Link attributes are flooded by IGP algorithms
- Information is stored in the Traffic Engineering Database (TED)

MPLS-TE Operation

Components:

1) Link Information Distribution
2) Path Calculation (CSPF)
3) Path Setup (RSVP-TE)
4) Forwarding through LSPs

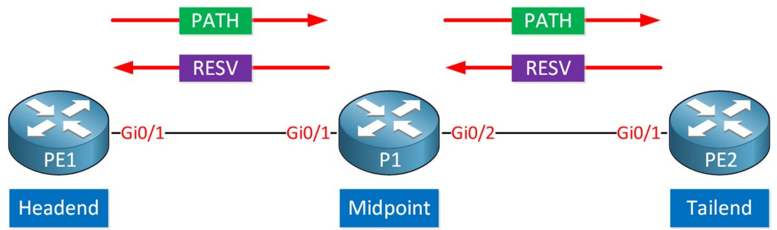
- Constrained Shortest Path First (CSPF) Algorithm
- Tunnel's *headend* runs CSPF providing TED and QoS requirements as inputs
- CSPF returns a list of potential next-hop IPs for the tunnel

MPLS-TE Operation

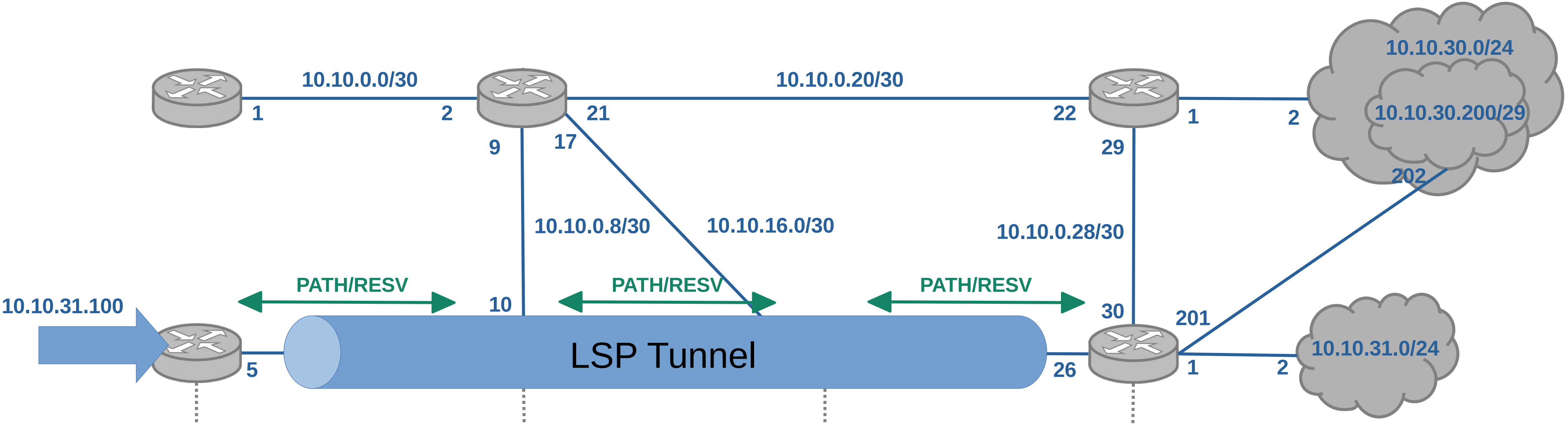
Components:

1) Link Information Distribution
2) Path Calculation (CSPF)
3) Path Setup (RSVP-TE)
4) Forwarding through LSPs

- Resource reservation through a signaling protocol, e.g., Resource Reservation Protocol TE (RSVP-TE)
- RSVP-TE:
  - Path setup and maintenance
  - Path teardown
  - Error signaling
- LFIB is populated with RESV labels



MPLS-TE Forwarding



Route	Mask	Label
10.10.30.200	/29	2
10.10.30.0	/24	3
10.10.31.0	/24	2

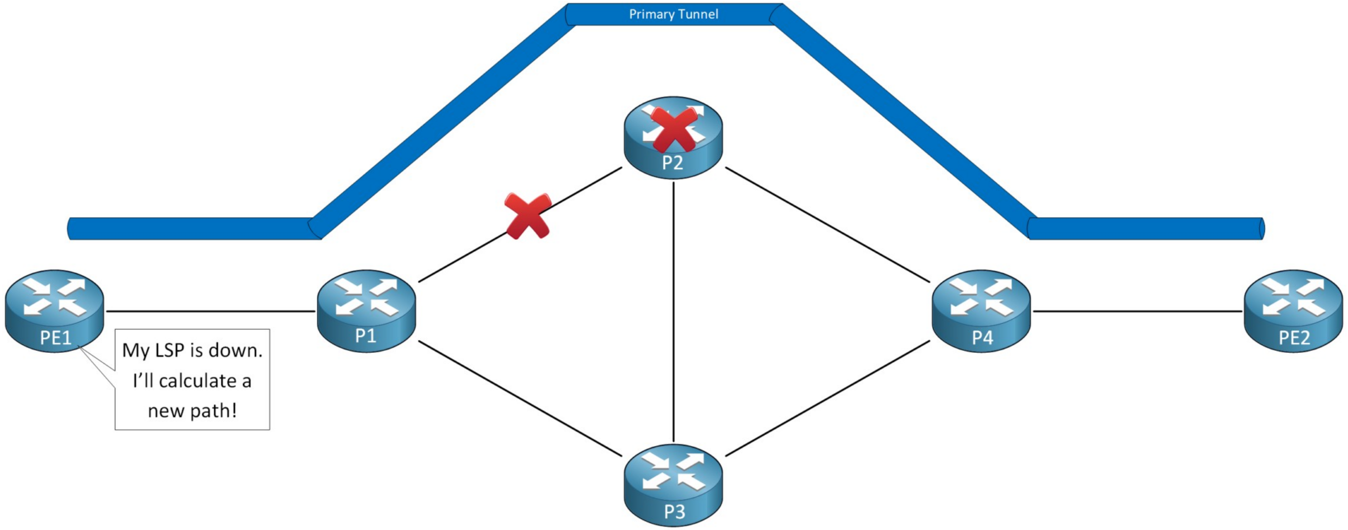
Label In	Label Out
2	1

Label In	Label Out
1	0

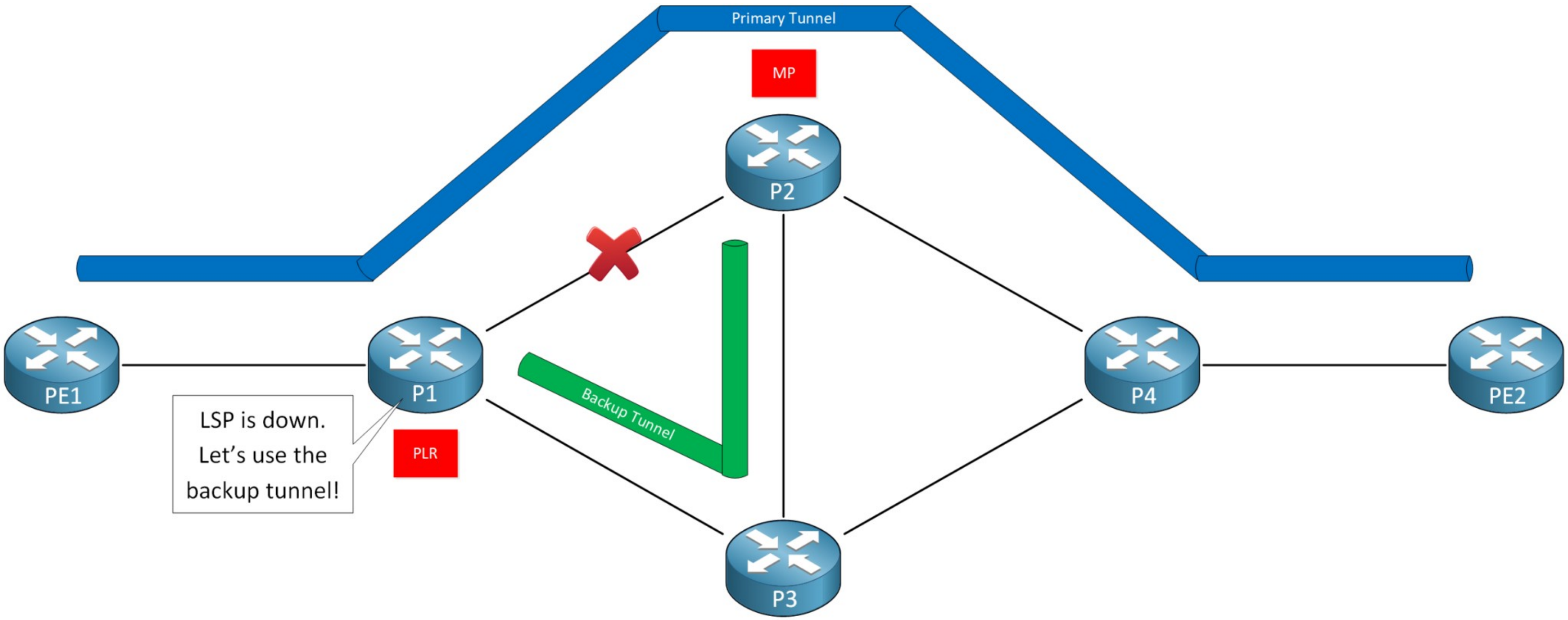
Route	Mask	Next Hop
10.10.30.200	/29	10.10.30.202
10.10.30.0	/24	10.10.0.29
10.10.31.0	/24	10.10.31.2

MPLS-TE Fast Reroute

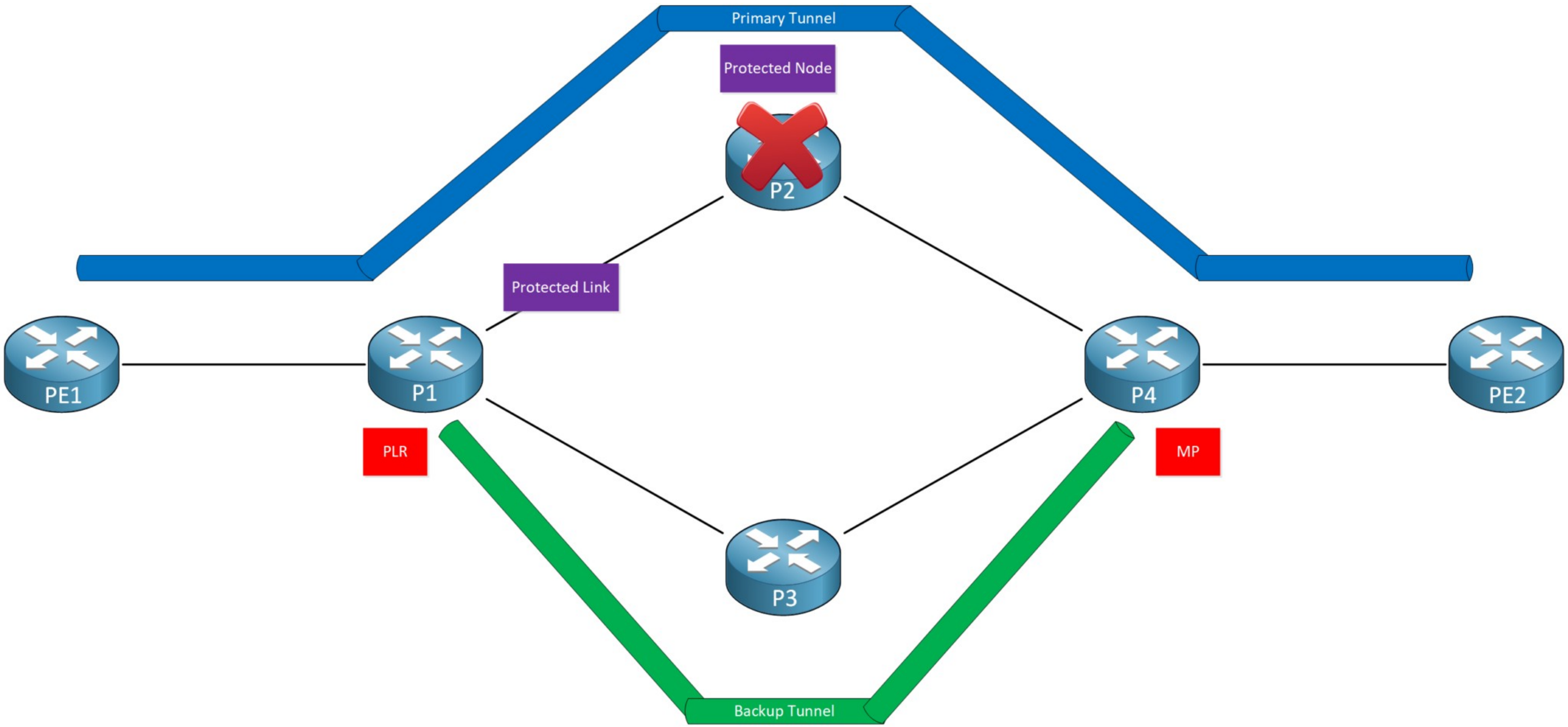
- MPLS-TE Fast Reroute (FRR) is a mechanism to recalculate routes in near real time (<50ms) upon network failures, i.e.,
  - When node or link becomes out-of-service
  - When node or link is no longer able to satisfy QoS requirements



MPLS-TE FRR: Link Protection



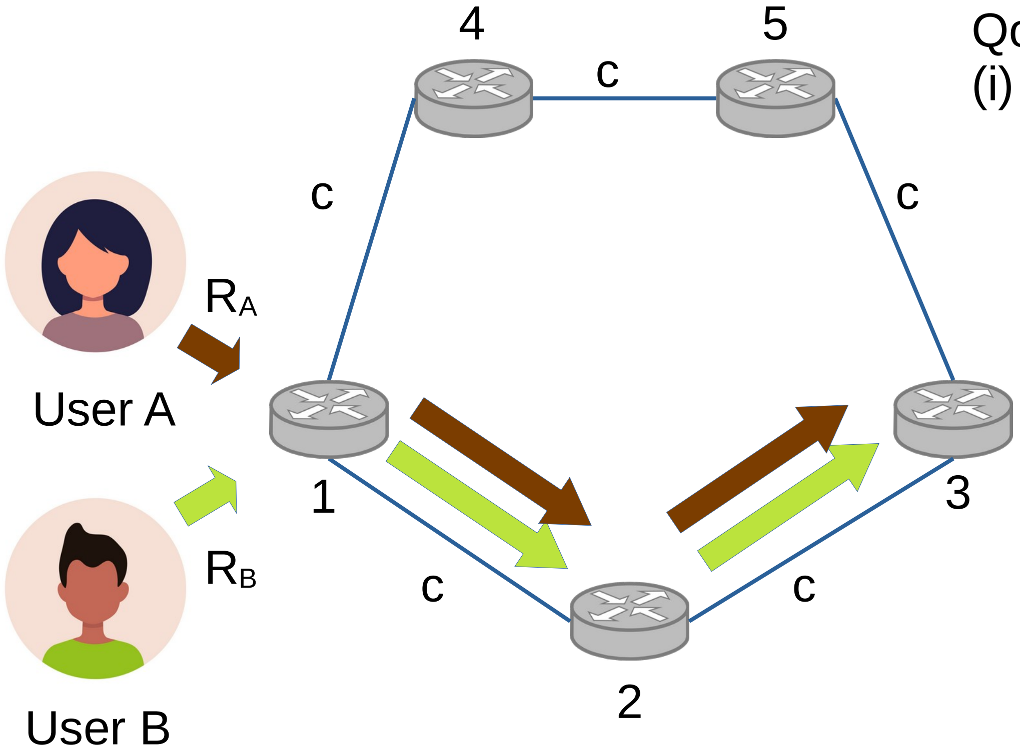
MPLS-TE FRR: Node Protection



MPLS-TE FRR Backups

- Backup tunnels are calculated by CSPF
- Types of backup:
  - One-to-one Backup (1:1)
  - Many-to-one (Facility) Backup (1:N)
- Primary tunnel's traffic is promptly redirected to the backup tunnel upon a switchover trigger, e.g.,
  - Failure detection
  - QoS requirement violation

Example 1

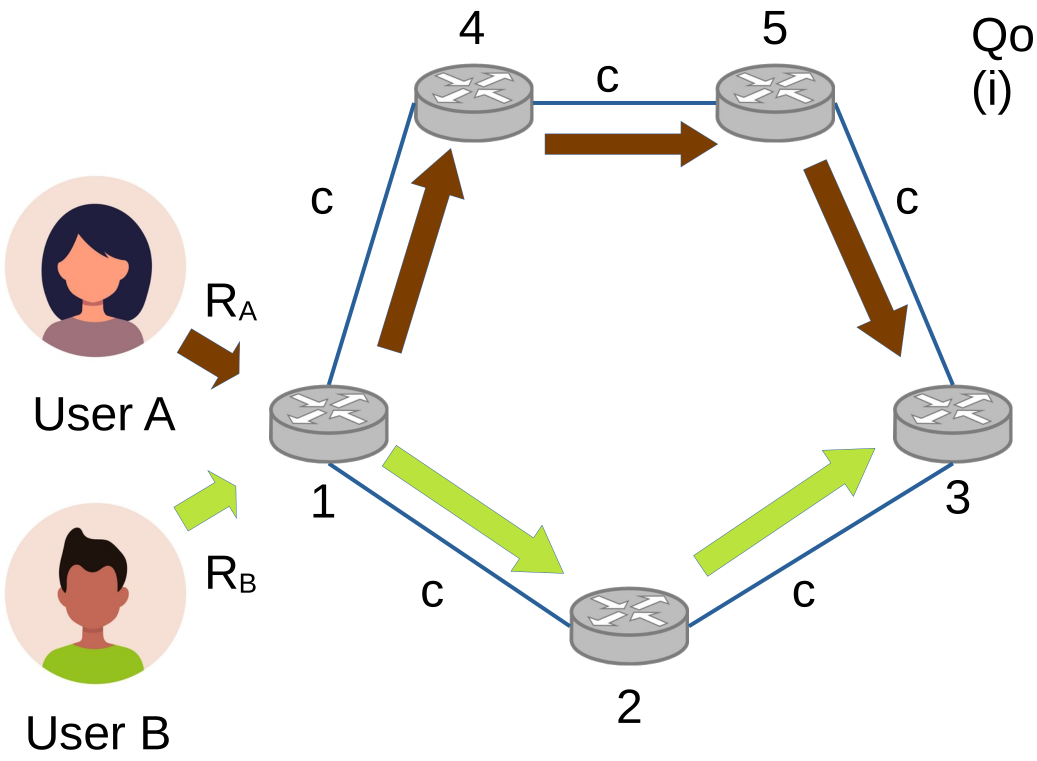


QoS Requirements:
(i) Throuhput < c in each link

$R_A = R_B = 450$ Mbps
c = 1 Gbps
Prop. delay of each link is d

If users double their rates, how can we steer the traffic to accommodate the new rates?

Example 1 - Solution

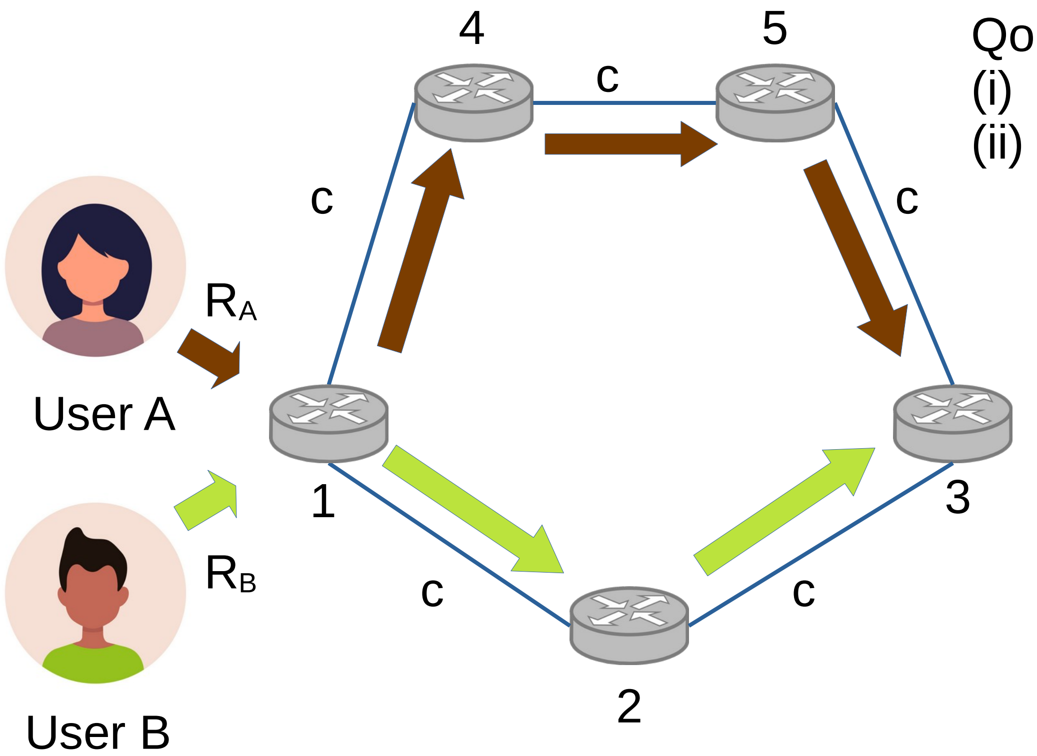


QoS Requirements:
(i) Throuhput < c in each link

$R_A = R_B$ = 900 Mbps
c = 1 Gbps
Prop. delay of each link is d

If users double their rates, how can we steer the traffic to accommodate the new rates?

Example 2

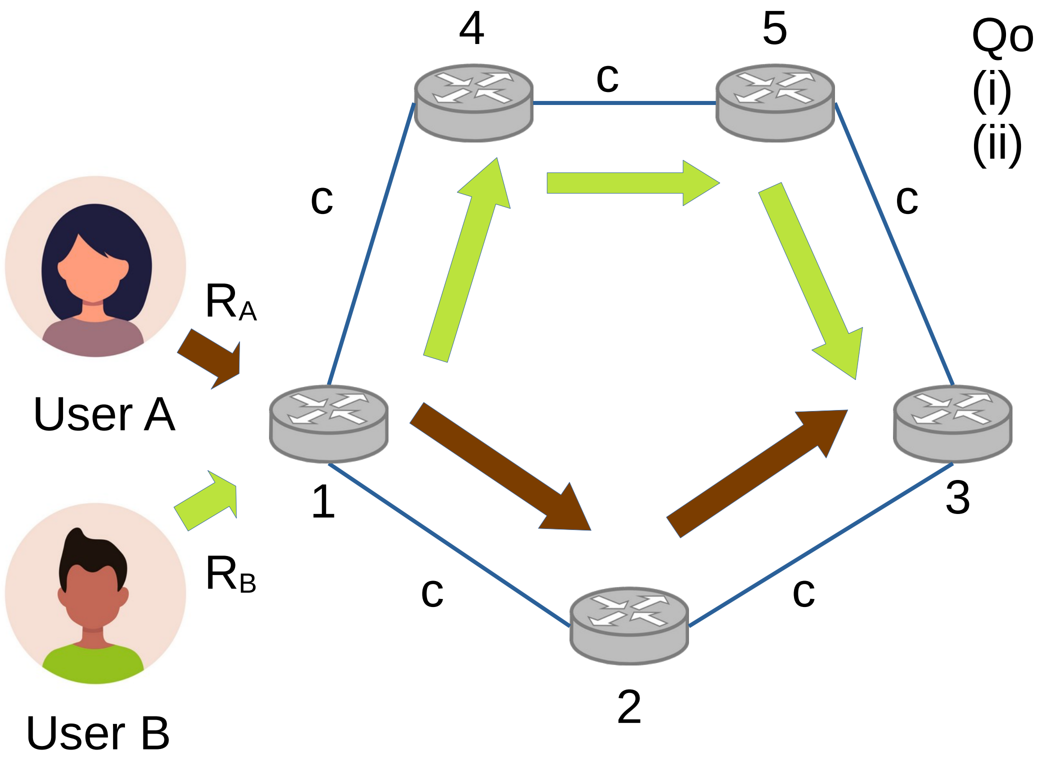


QoS Requirements:
(i) Throuhput < c in each link
(ii) Traffic A's prop delay < 3d

$R_A = R_B = 900$ Mbps
c = 1 Gbps
Prop. delay of each link is d

Does QoS Requirement (ii) cause to change the current solution?

Example 2 - Solution

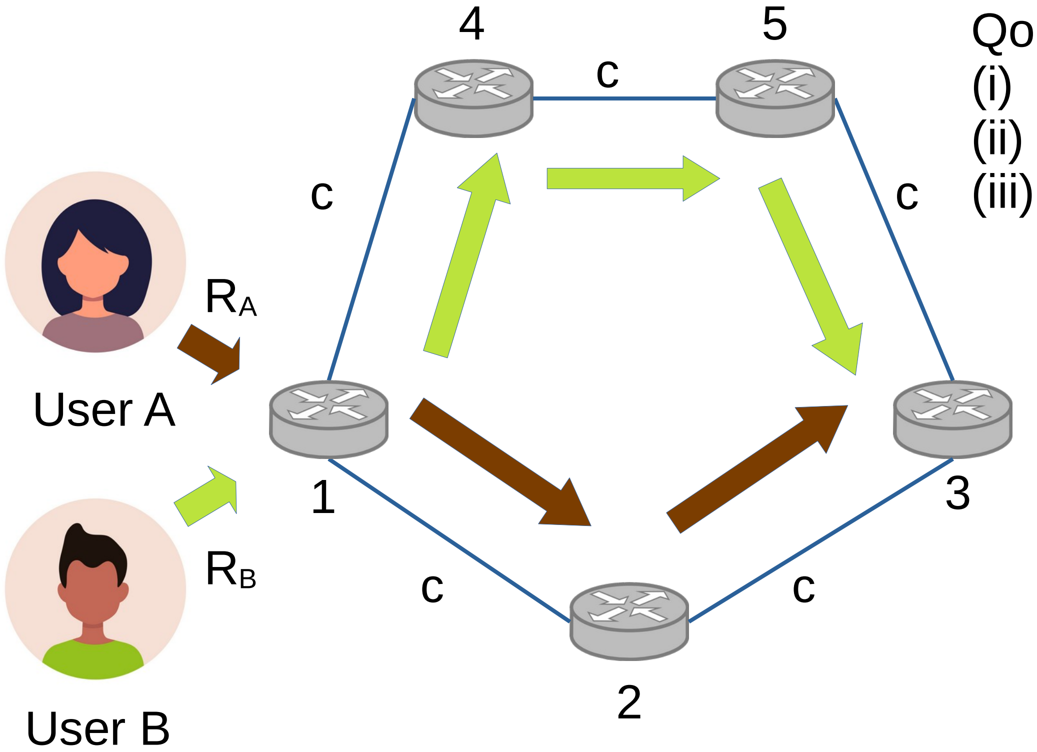


QoS Requirements:
(i) Throuhput < c in each link
(ii) Traffic A's prop delay < 3d

$R_A = R_B = 900$ Mbps
c = 1 Gbps
Prop. delay of each link is d

Does QoS Requirement (ii) cause to change the current solution?

Example 3



QoS Requirements:
(i) Throuhput < c in each link
(ii) Traffic A's prop delay < 3d
(iii) Traffic B's queuing delay < $(c\text{-}R_B)^{-1}$

Recall that, for MM1 systems, queuing delay is:

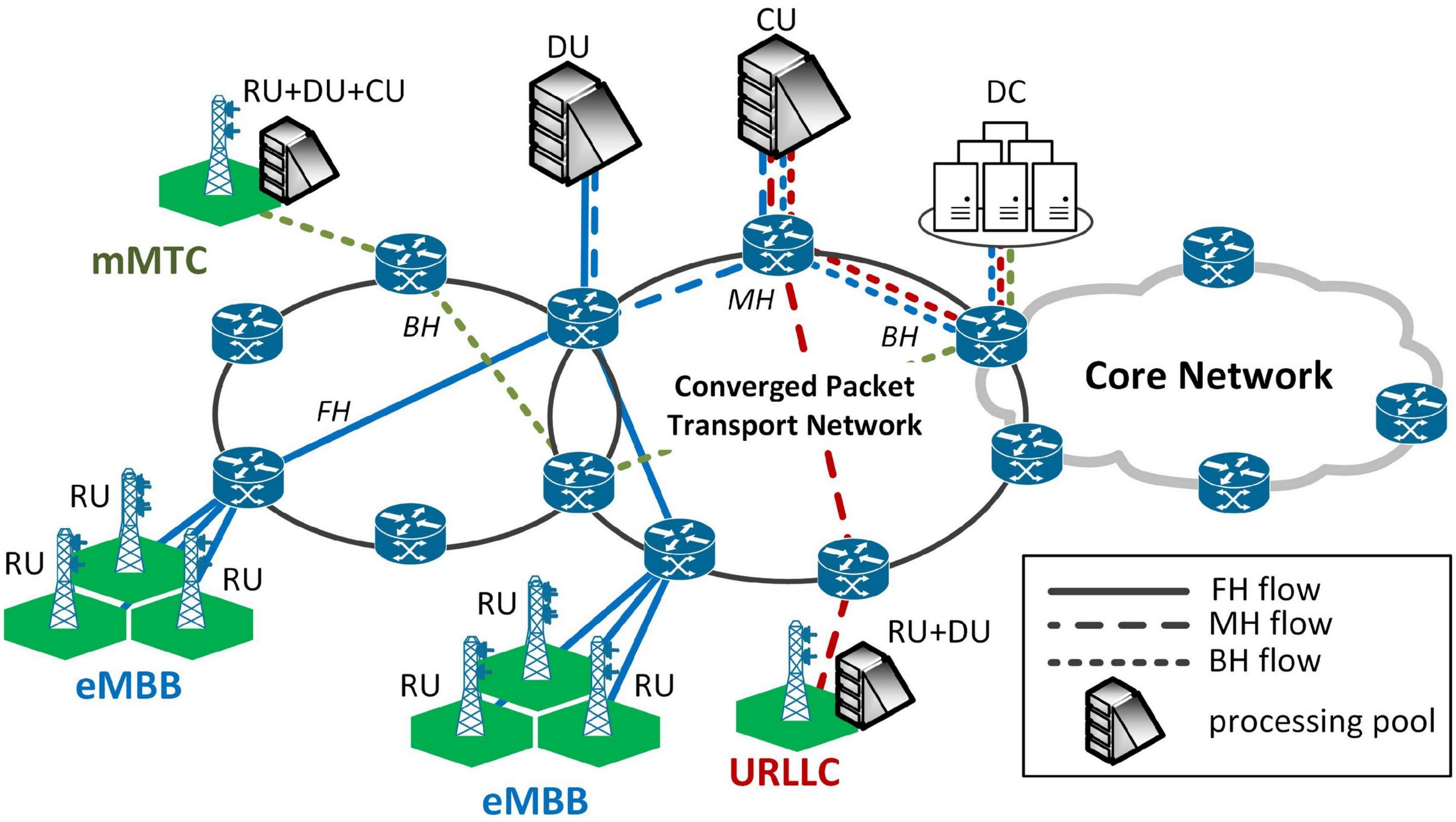
$$\forall i, D_i^Q := \frac{1}{c - \sum_{u \in \{A,B\} : i \in F_u} R_u}$$

$R_A = R_B = 900$ Mbps
c = 1 Gbps
Prop. delay of each link is d

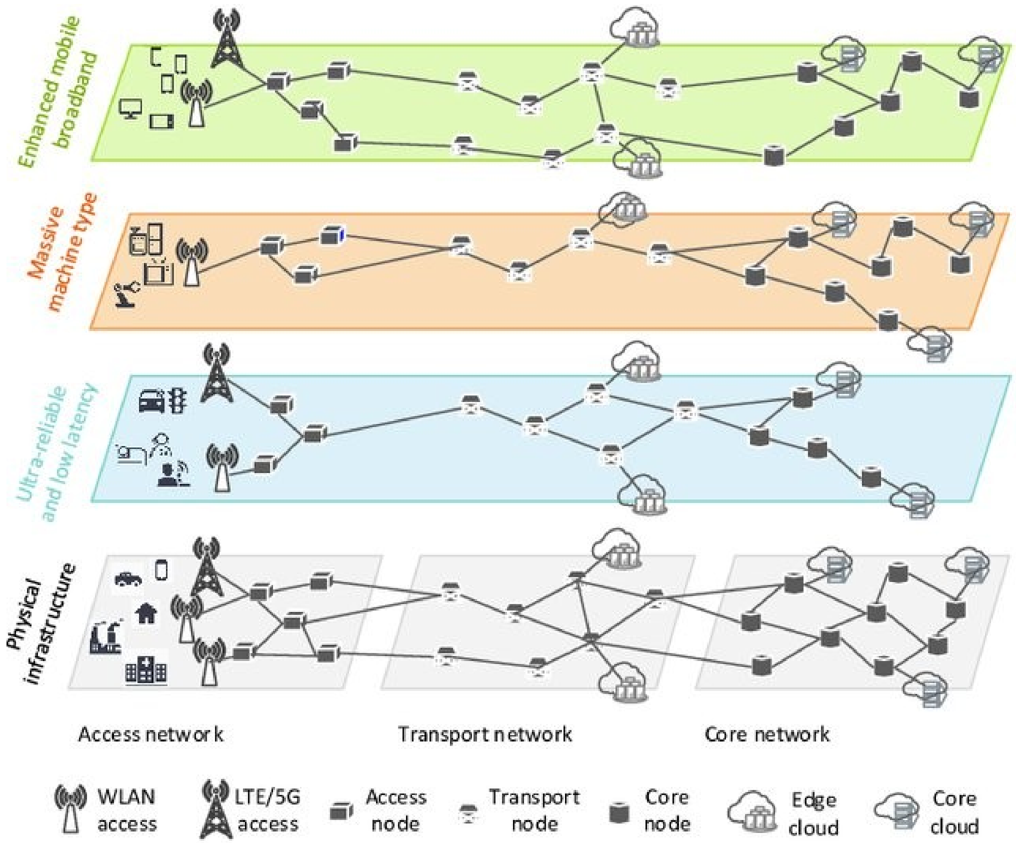
Can the current tunnels satisfy requirement (iii)? If not, what can you change/implement to satisfy all requirements.

QoS in 5G

5G Infra Overview

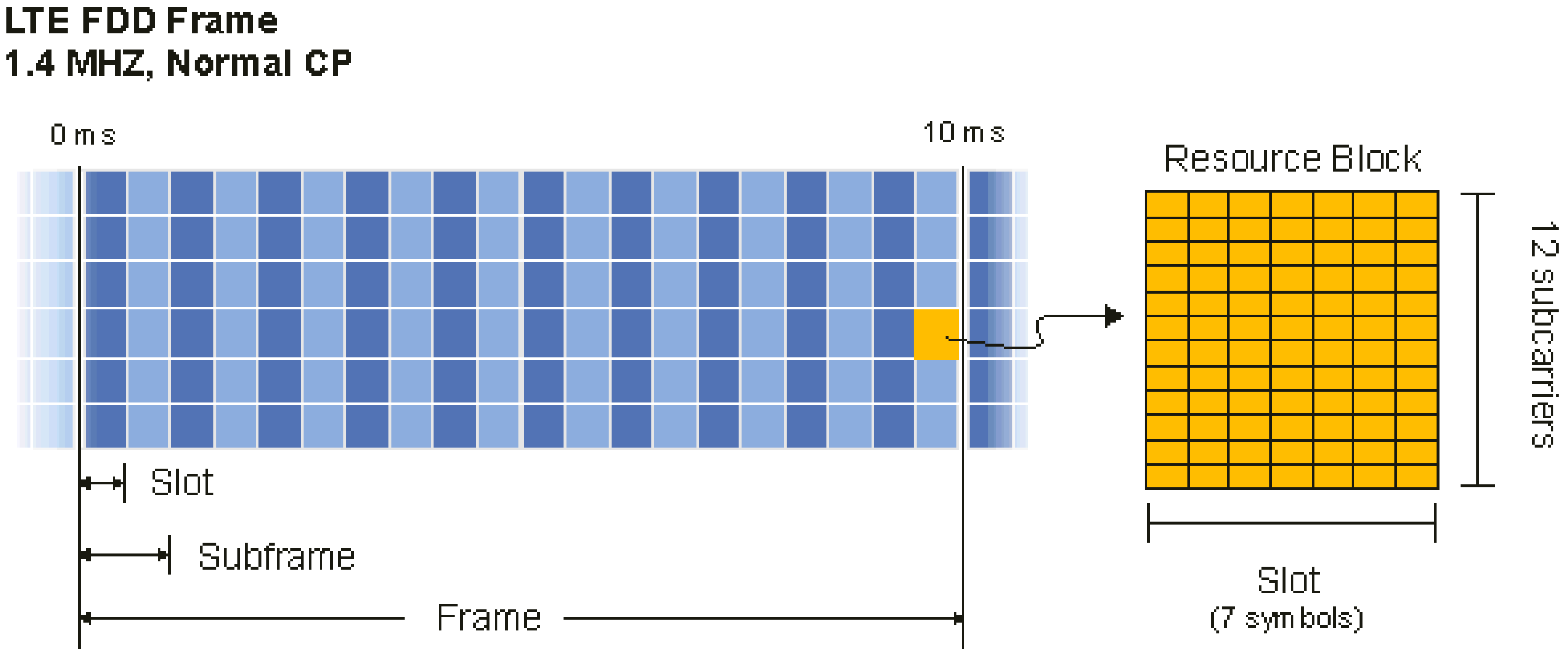


QoS as 5G Slicing



W. Guan, X. Wen, L. Wang, Z. Lu and Y. Shen, "A Service-Oriented Deployment Policy of End-to-End Network Slicing Based on Complex Network Theory," in IEEE Access, vol. 6, pp. 19691-19701, 2018, doi: 10.1109/ACCESS.2018.2822398.

OFDMA’s RBs and RBGs



Quota Algorithm

Algorithm 1 Calculating RBGs quota for slices

variable rbs_offset_
procedure SLICEQUOTA
    rbs_share = []
    rbgs_quota = []
    k $\leftarrow$ rbs_per_rbg()
    for s in $\mathcal{S}$ **do**
        rbs_share[s] $\leftarrow |\mathcal{RB}| \times w_s$ - rbs_offset_[s]
        rbgs_quota[s] $\leftarrow \lfloor$ rbs_share[s] / k $\rfloor$
    end for
    extra_rbgs = $|\mathcal{RBG}|$ - sum(rbgs_quota)
    while extra_rbgs > 0 **do**
        rbgs_quota[$\mathcal{S}.rand()$] += 1
        extra_rbgs -= 1
    end while
    for s in $\mathcal{S}$ **do**
        rbs_offset_[s] = rbgs_quota[s] $\times$ k - rbs_share[s]
    end for
    return rbgs_quota
end procedure

Quota Algorithm Example