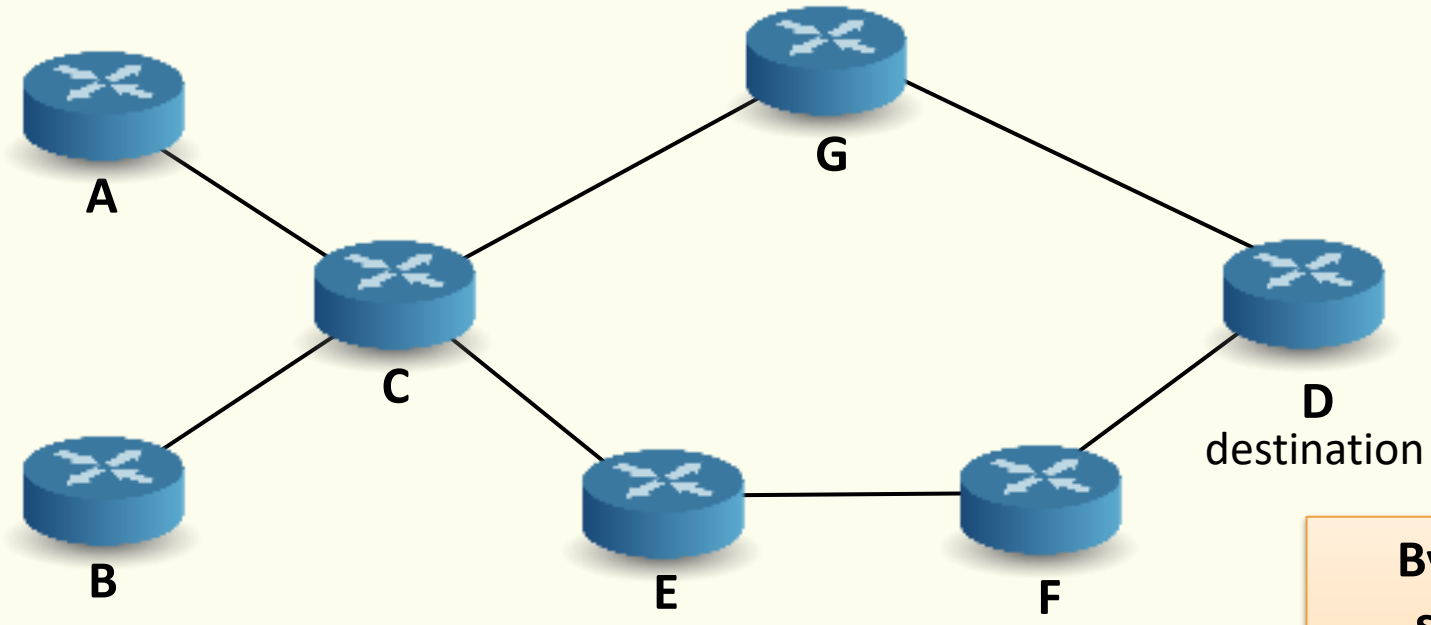
Requirements for TE



Computing paths that comply with a set of constraints

Enforcing traffic to be forwarded along these paths

By decoupling service from transport, MPLS is fundamental to support TE requirements

Constraint-based routing

- A set of **algorithms** and **protocols** that enable a router to compute a path to a destination which
  - is **optimal** with respect to a certain **scalar metric**
  - does not violate **a set of constraints**

- Traditional IP routing path computation is only driven by cost optimization (objective)
  - Cost measures need to be overloaded to enable IP traffic engineering

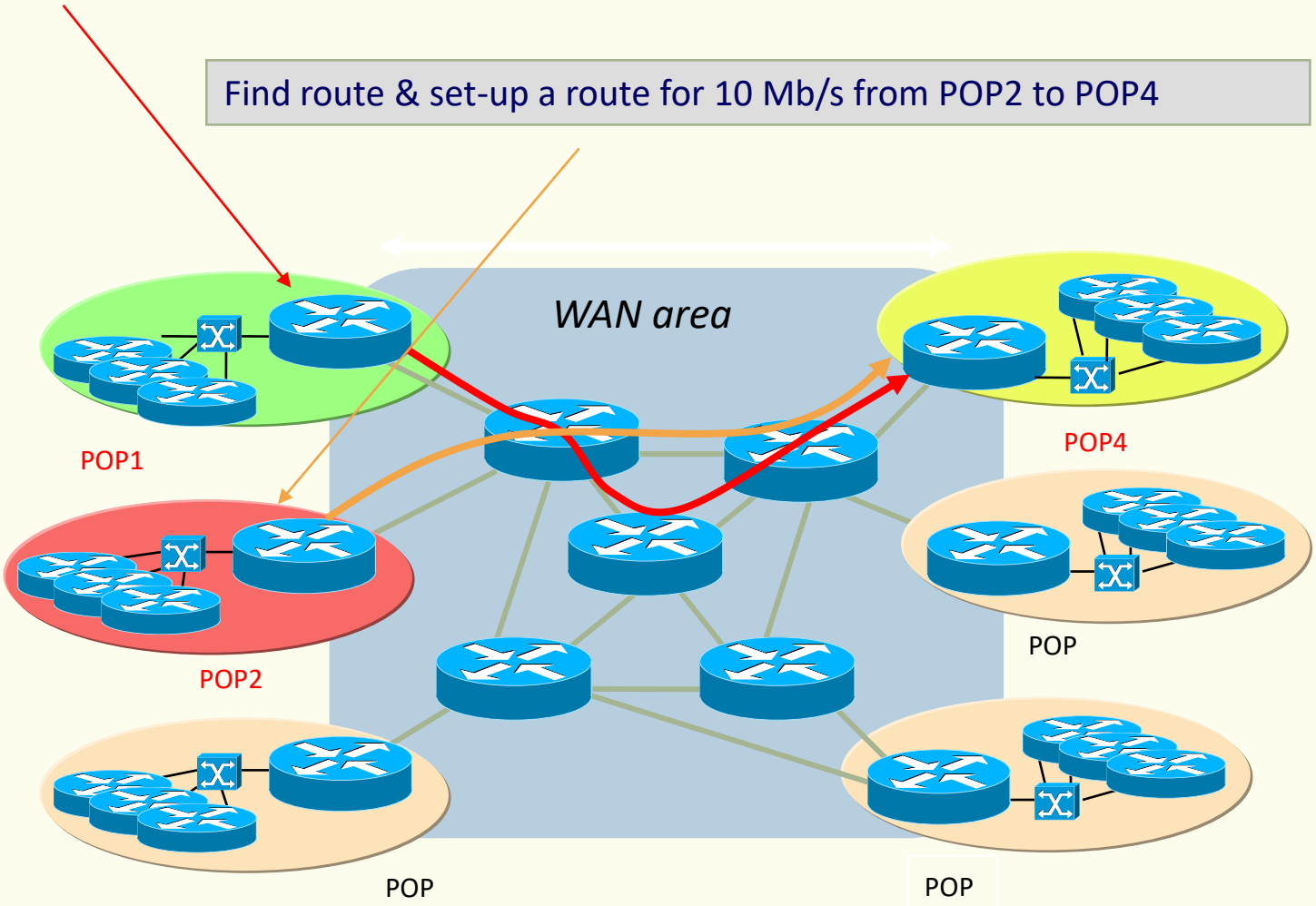
Type of constraints

- **Performance constraints**
  - a path with certain minimum available bandwidth on each traversed link
  - a path with a maximum number of hops
  - a path optimizing a specific TE metric
- **Administrative constraints**
  - include only links that are tagged with specific attributes
  - exclude from the path a specific hop
- **Complex combinations**
  - place two related LSPs on different links

Type of constraints

Find route & set-up a route for 20 Mb/s from POP1 to POP4

Find route & set-up a route for 10 Mb/s from POP2 to POP4



Constraint-based routing

1. **Link characterization** (in a consistent manner)
   – Cost and attributes
2. **Extended routing protocol**
   – To convey the enriched link characterization
3. **Constraint-based path computation algorithm**
   – Constrained Shortest Path First (CSPF)

Link characterization

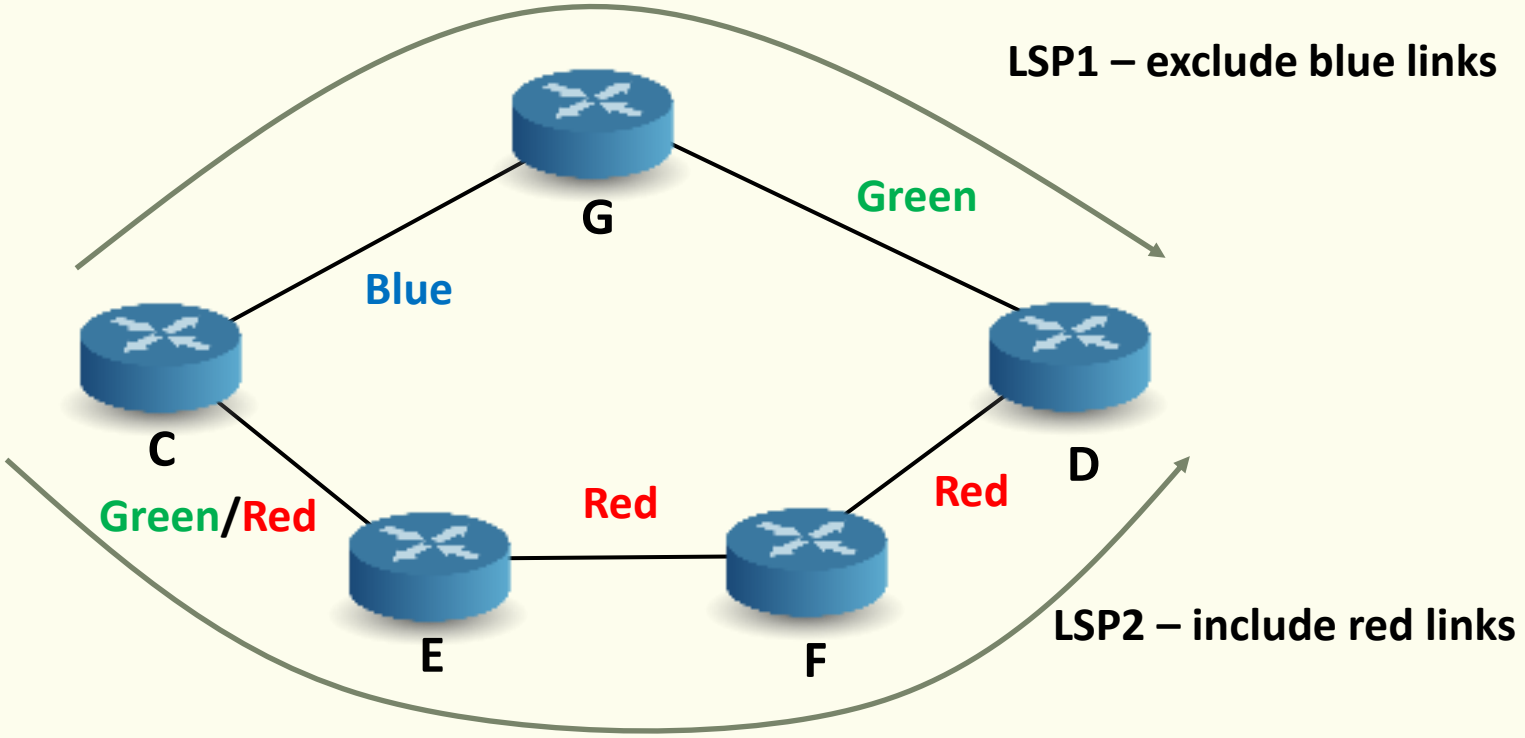
- **Traffic Engineering Metric**
  - Specifies the link metric (i.e., the cost) for traffic engineering purposes
  - This metric may be different than the standard OSPF link metric
  - Typically, the metric is assigned by a network administrator

Link characterization

- **Maximum Bandwidth**, i.e., the link bandwidth that is usable
- **Maximum Reservable Bandwidth**, i.e., the amount of bandwidth that can be reserved on a link
  - This is normally configured to be smaller than (or equal to) the Maximum Bandwidth, unless the administrator wants the link to be oversubscribed
- **Unreserved Bandwidth**, i.e., the amount of bandwidth still available on the link (*per priority level*)

Link characterization

- **Administrative Group** (or color)
  - A link can be a member of up to 32 groups



Constraint-based routing

1. **Link characterization** (in a consistent manner)
   – Cost and attributes
2. **Extended routing protocol**
   – To convey the enriched link characterization
3. **Constraint-based path computation algorithm**
   – Constrained Shortest Path First (CSPF)

Extended routing protocols

- Link attributes must be **advertised** as part of routing information by the routing protocol
- Link-state vs. Distance-vector?
- Existing link-state protocols have been **extended** to support contraint-based routing
  - OSPF → OSPF-TE
  - IS-IS → IS-IS-TE

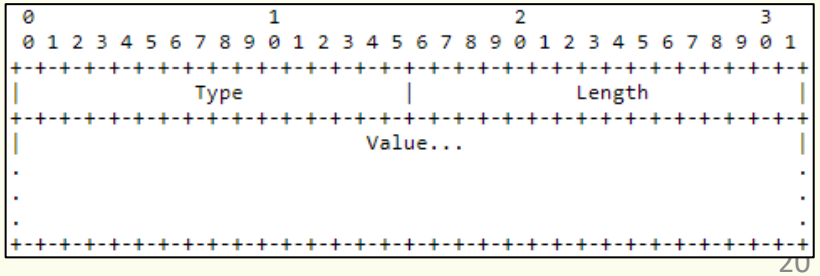
OSPF-TE [rfc 3630]

- **Traffic Engineering LSA**. Similar to Router LSA, it describes
  - Routers
  - Point-to-point links
  - Connections to multi-access networks
- **Limitations**
  - Only Opaque LSAs of Type 10 is used, that has **area wide flooding scope**
  - Only the **reservation state of p2p links** is captured

OSPF-TE [rfc 3630]

The LSA payload consists of **one** of two top-level TLV triplets:

1. **Router Address**: specifies a stable IP address; this is typically implemented as a *loopback address*
2. **Link**: describes a single link, using a set of sub-TLV triplets
    1. Link type (1 octet): p2p or multi-access
    2. Link ID (4 octets)
    3. Local interface IP address (4 octets)
    4. Remote interface IP address (4 octets)
    5. **Traffic engineering metric** (4 octets)
    6. **Maximum bandwidth** (4 octets)
    7. **Maximum reservable bandwidth** (4 octets) *for each setup pritority*
    8. **Unreserved bandwidth** (32 octets)
    9. **Administrative group** (4 octets)



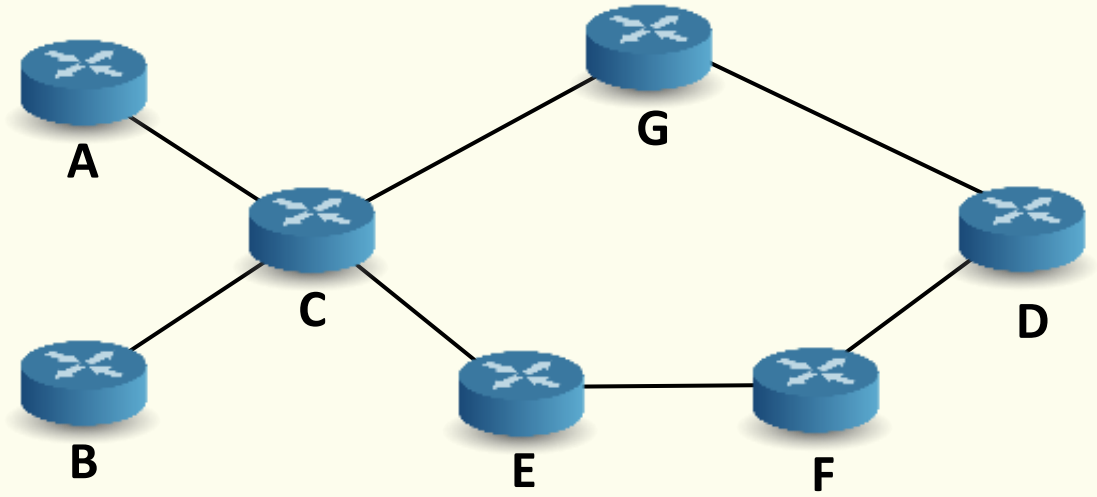
Traffic Engineering Database

- Each router has knowledge of the values of all **attributes** of all links **in a single area**
- Link attributes are stored in the Traffic Engineering Database (TED)
  - **Static** link attributes
    - Maximum Bandwidth or Administrative Groups
  - **Dynamic** link attributes
    - Unreserved bandwidth

When to distribute link state updates?

Traffic Engineering Database

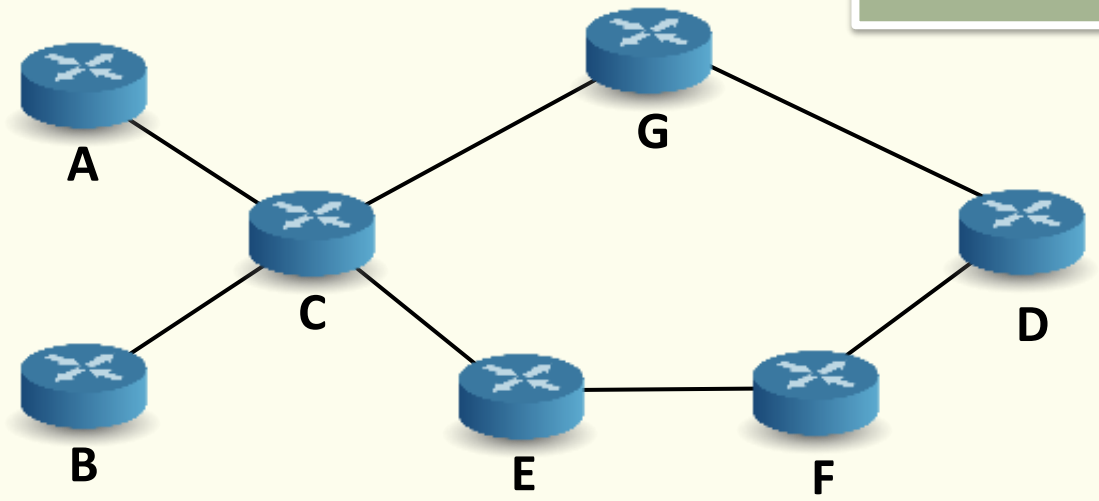
- **Link status change**, as with regular OSPF
  - State of the interface (up/down)
  - Manual configuration change



Traffic Engineering Database

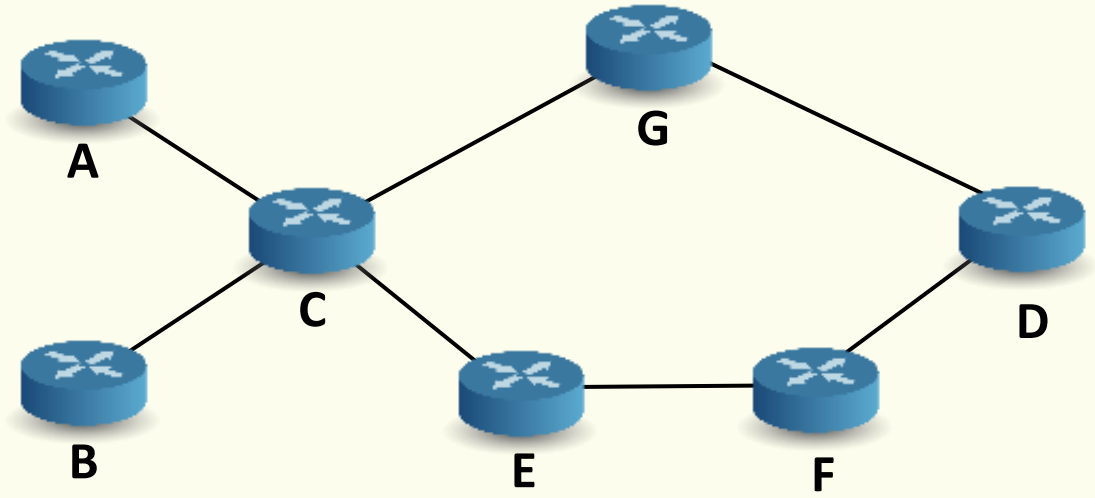
- **TE-related status change**
  - Change in the Unreserved Bandwidth: a router can be configured so that flooding is triggered only if the UB crosses certain thresholds

How to configure thresholds?



Traffic Engineering Database

- **TE-related status change**
  - LSP setup failure



Traffic Engineering Database

- **Periodic**
  - Needed to complement changes that do not trigger an update (180s by default on Cisco routers)

- Thesholds help reducing control traffic overhead
- TEDs are not 100% up to date and therefore path computation is **not always accurate**

Constraint-based routing

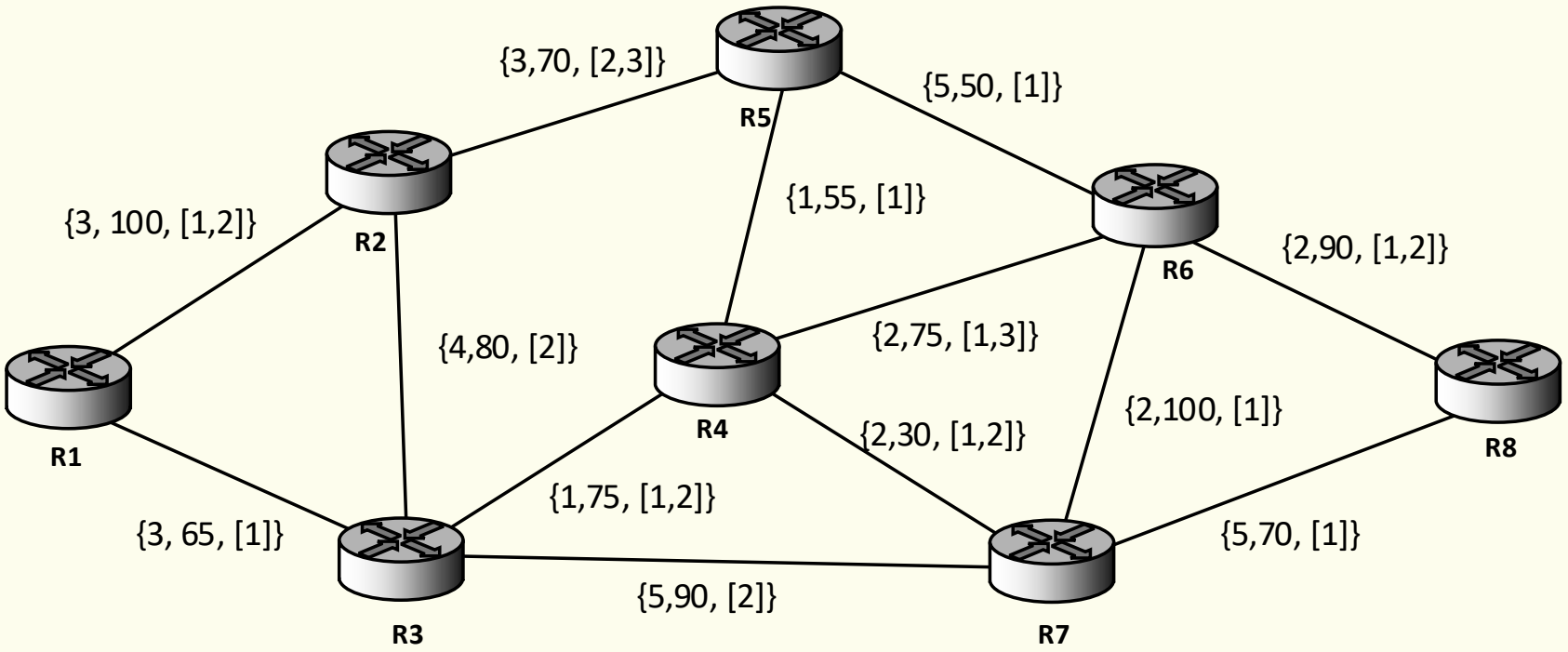
1. **Link characterization** (in a consistent manner) beyond the cost
   - Attributes
2. **Extended routing protocol**
   - To convey the enriched link characterization
3. **Constraint-based path computation algorithm**
   - Constrained Shortest Path First (CSPF)

Constraint-based path computation

- Constrained Shortest Path First algorithm is used
  - Path metric
  - Local (LSP specific) constraints on link attributes
  - TED content
- Enhanced version of Dijkstra's algorithm (SPF)
  - apply the constraints to all the links in the TED, so as to obtain a "**pruned**" network graph
  - apply **SPF** on the pruned network graph so as to find the Shortest Path Tree that connects the source to any reachable destination

CSPF example

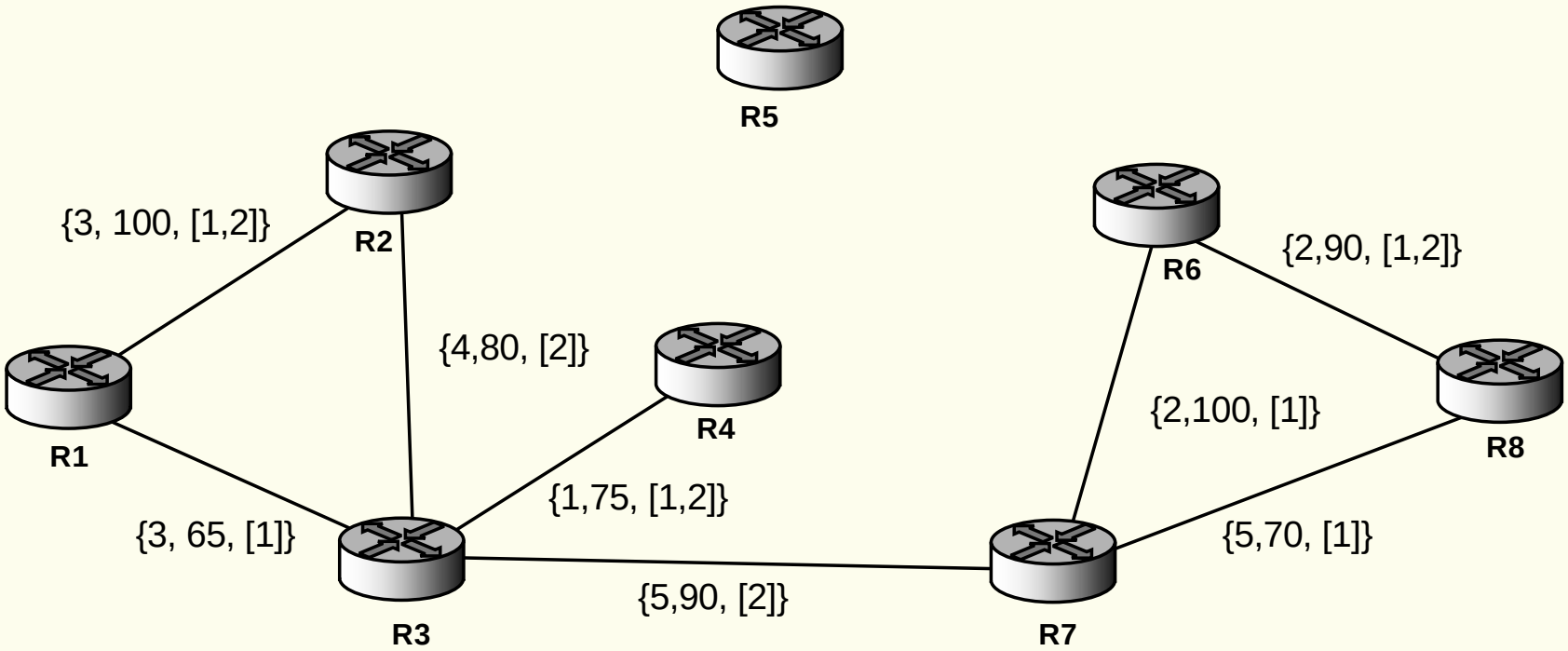
{Cost, Unreserved bandwidth, [Groups]}



LSP: R1→R8, 60Mb/s, exclude Group 3

CSPF example

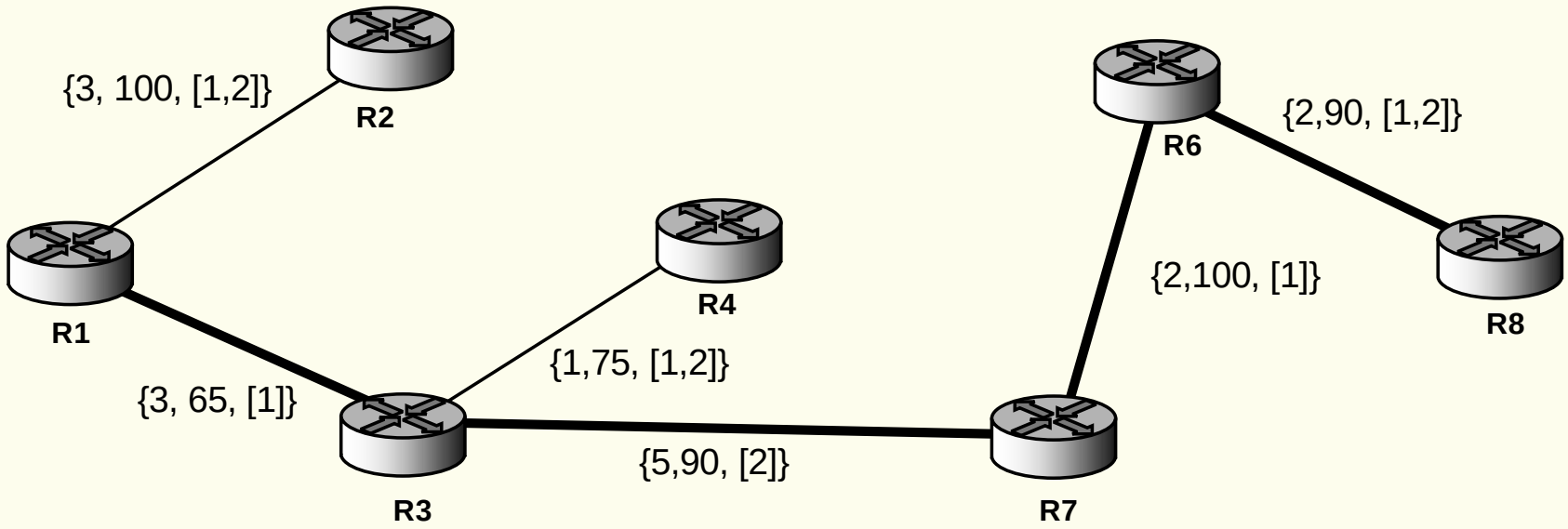
{Cost, Unreserved bandwidth, [Groups]}



LSP: R1→R8, 60Mb/s, exclude Group 3

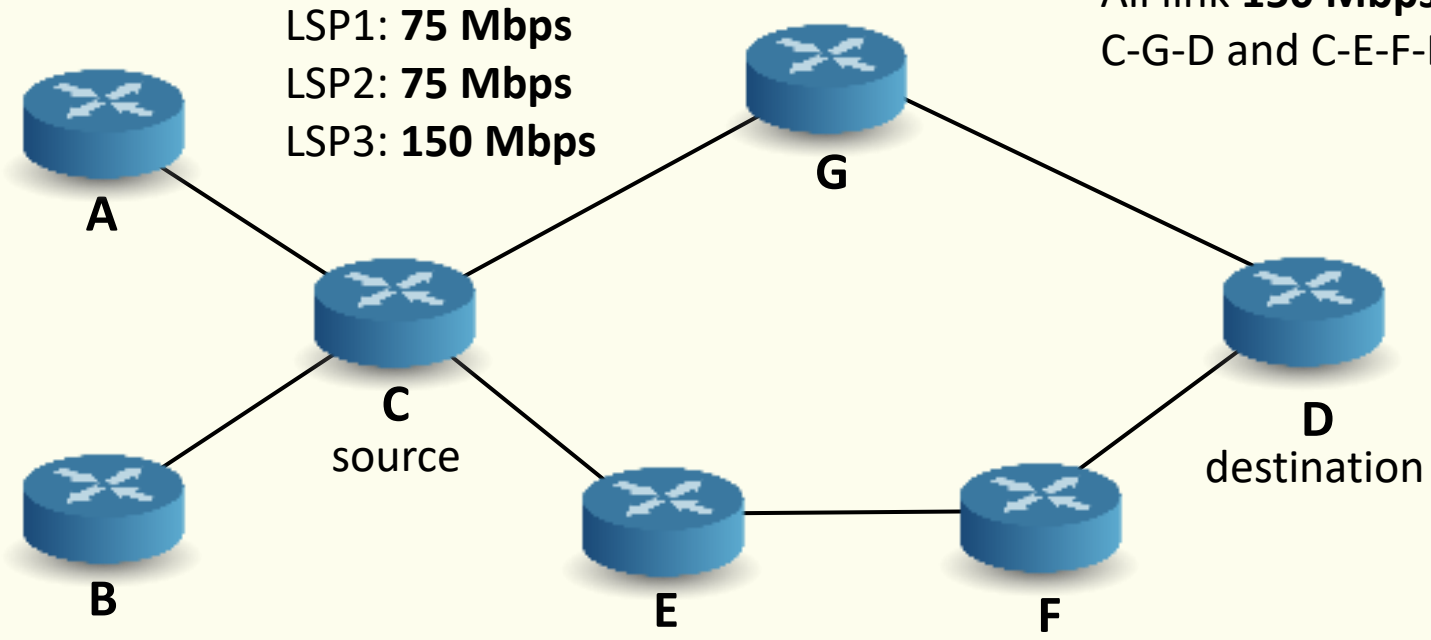
CSPF example

{Cost, Unreserved bandwidth, [Groups]}



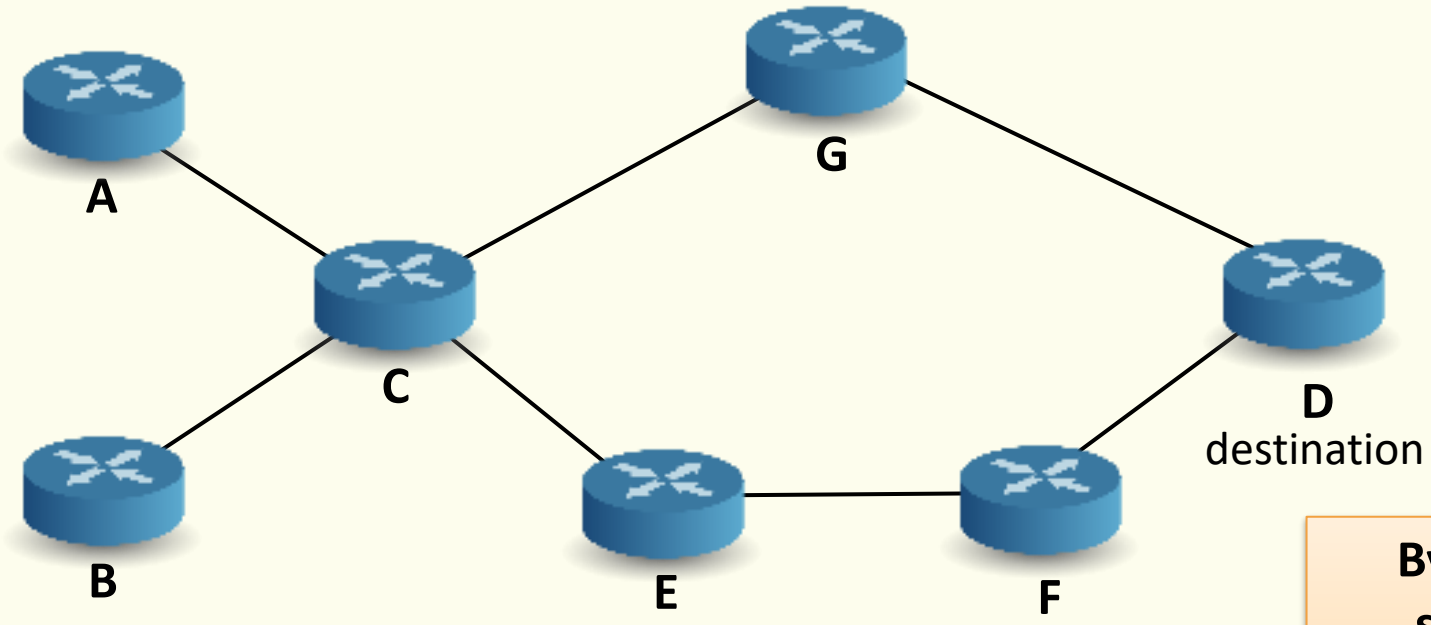
LSP: R1→R8, 60Mb/s, exclude Group 3

Tie-breaking rules



1. **Largest minimum Unreserved Bandwidth first**: the path with the largest minimum Unreserved Bandwidth is selected
2. **Smallest minimum Unreserved Bandwidth first**: the path with the smallest minimum Unreserved Bandwidth is selected
3. **Random**

Requirements for TE



Computing paths that comply with a set of constraints

Enforcing traffic to be forwarded along these paths

By decoupling service from transport, MPLS is fundamental to support TE requirements