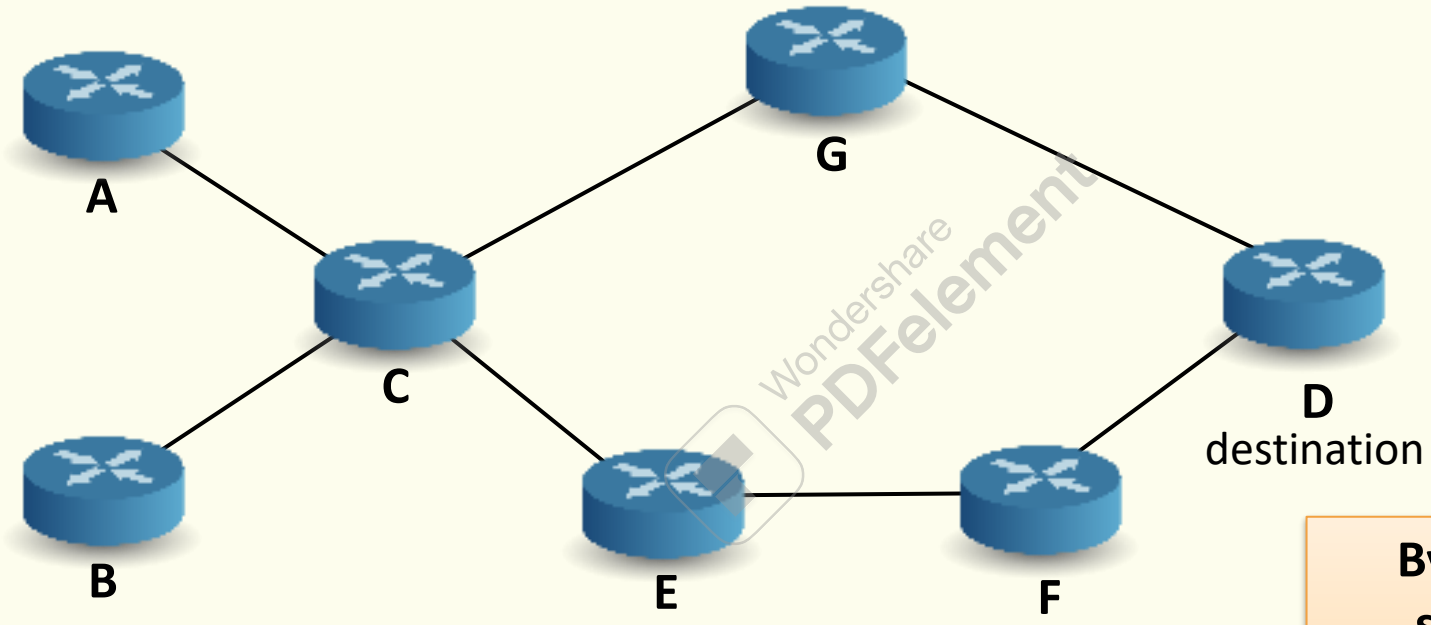
Requirements for TE



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**

Remember: Only End-to-End routers run this!

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

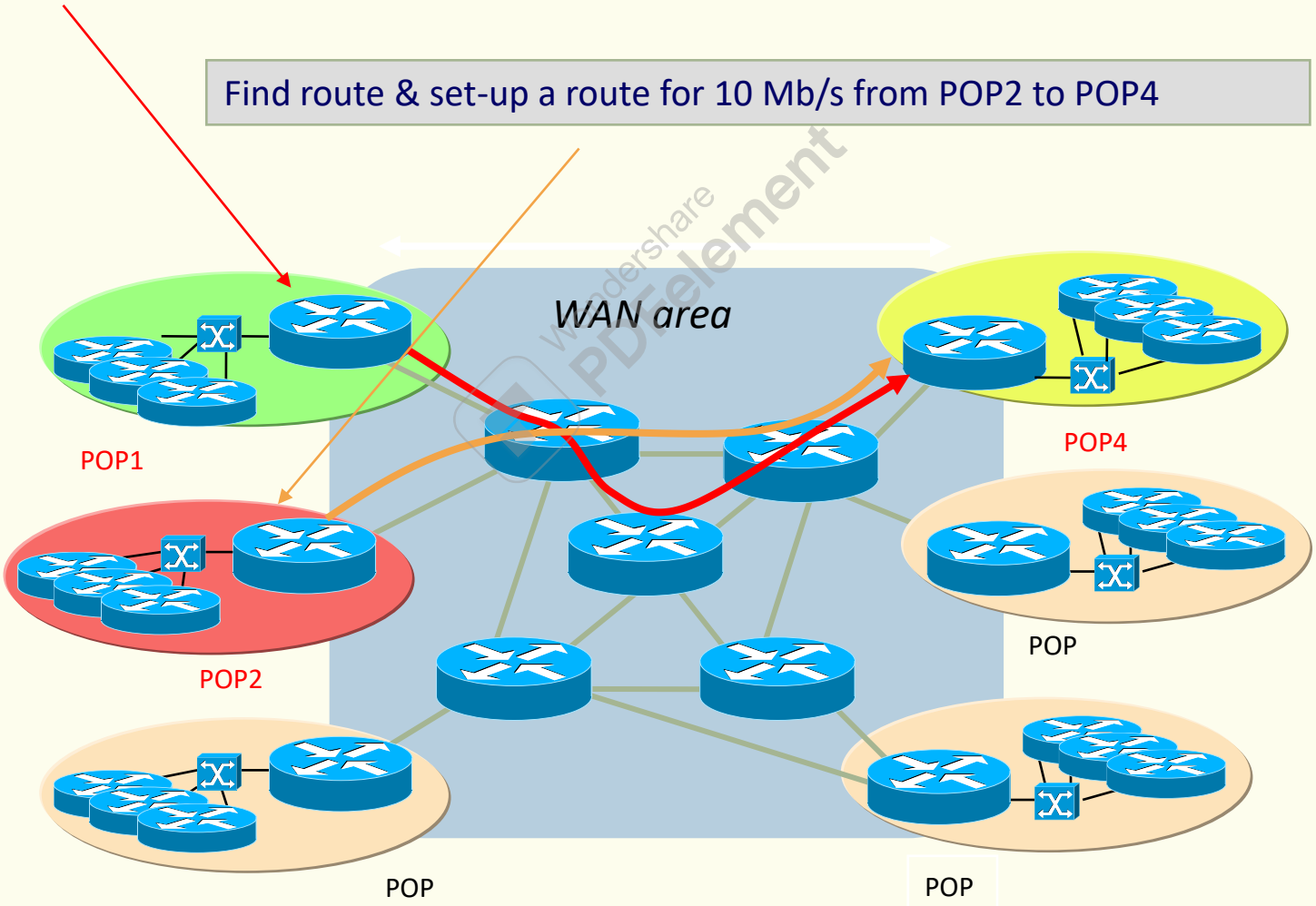
Type of constraints

- **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)

Routers will only be capable of routing based on a subset of all possible Link parameters

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

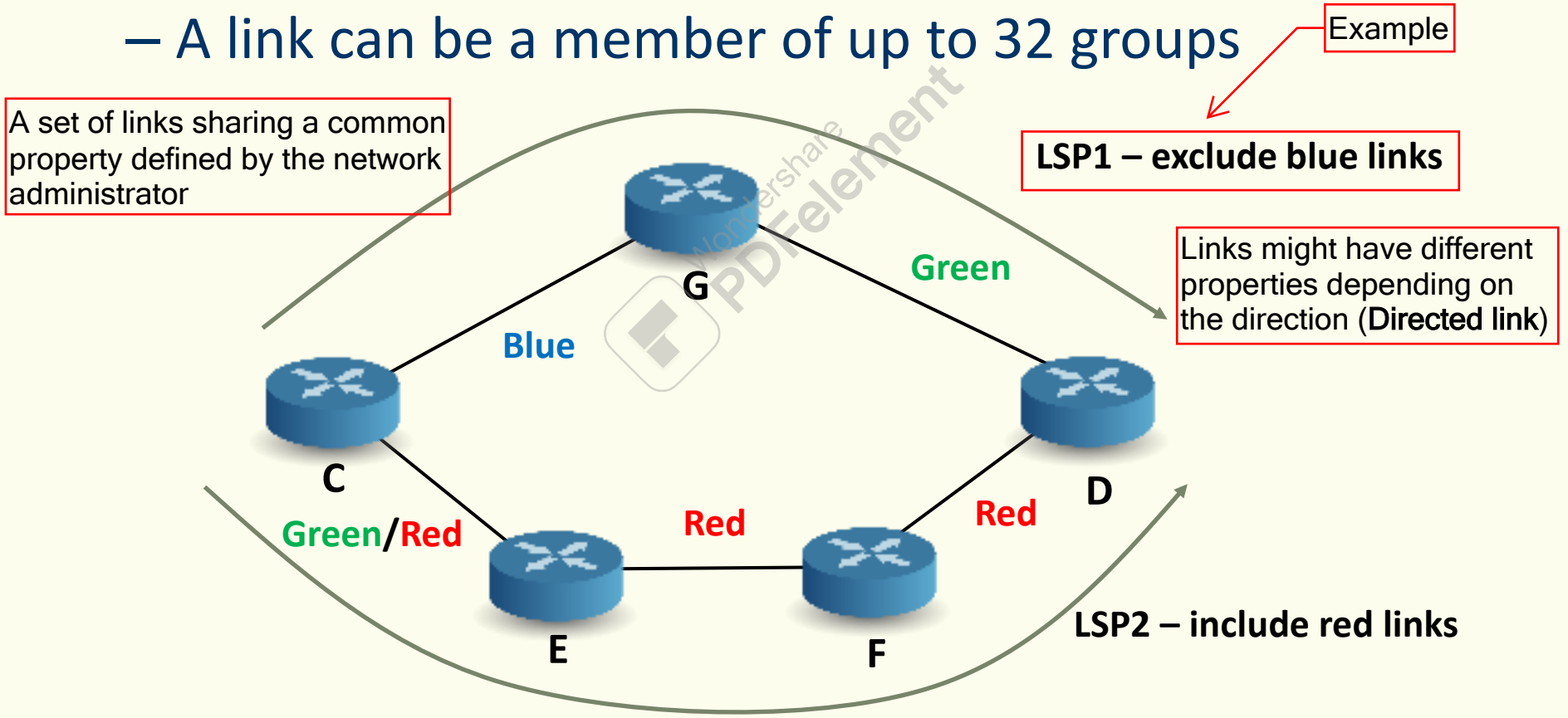
Link characterization

- **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

N = 32



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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

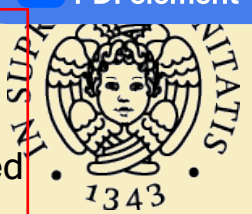
Their role is to collect the state/properties of the links and distribute this information across the network (via **Flooding**)

There is now new info apart from Cost that needs to be distributed over the network

LSA stands for **Link State Advertisement**. Each router stores in a db the this info, which is usually the cost of a link.

OSPF-TE [rfc 3630]

OSPF uses **Selective Flooding**. Each router sends LSAs to their neighbours, which then save and propagate this info only if it is different from the already stored info in the LSA Database.



- **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

LSA Type 5 messages are used by Boundary Routers to relay info to other BRs about external network reachability.

LSA Type 1 is the "usual" packet which carries the link info to the neighbours.

OSPF is a Hierarchical Algorithm. It can work on subdivisions of the Network called **Areas**. Each Area is isolated from the perspective of non-Border Routers.

LSA Type 3 is generated by **Area Boundary Routers** only. It acts as a **summary of the networks in an area**. It is used to discover which networks are in another Area, and their **cost from the ABR** used to access that Area.

This means that externally, it is only known that a network is in that Area, not how to reach it. It is an **Area-Scope**.

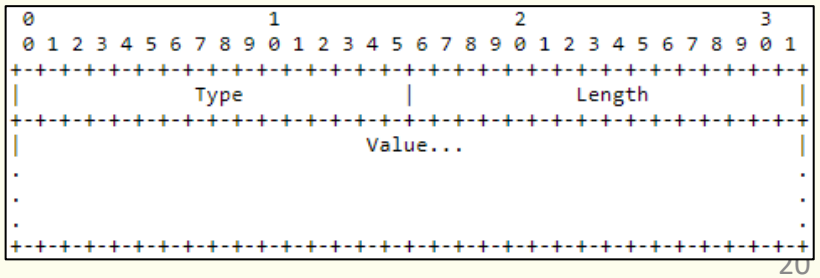
Opaque LSAs are packets that carry miscellaneous data. Routers only know that they have to propagate data, and don't care about the contents. Type 9 is Link-Scope, **Type 10 is Area-Scope**, Type 11 is AS-Scope.

Areas are needed for Scalability issues. Thus, Traffic Engineering is only limited to an Area scope. Costs are computed and summarised by ABRs, thus further protocols are needed to share the TE Constraints for a certain desired route.This will be the role of the RSVP which will be seen later.

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 ← Point-toPoint only.
    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) ← Complemenets the OSPF Database
  - **Static** link attributes
    - Maximum Bandwidth or Administrative Groups
  - **Dynamic** link attributes
    - Unreserved bandwidth

Information related to Topology is refreshed by OSPF every 30 minutes, but this is obviously too big of an interval for TE related uses.

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

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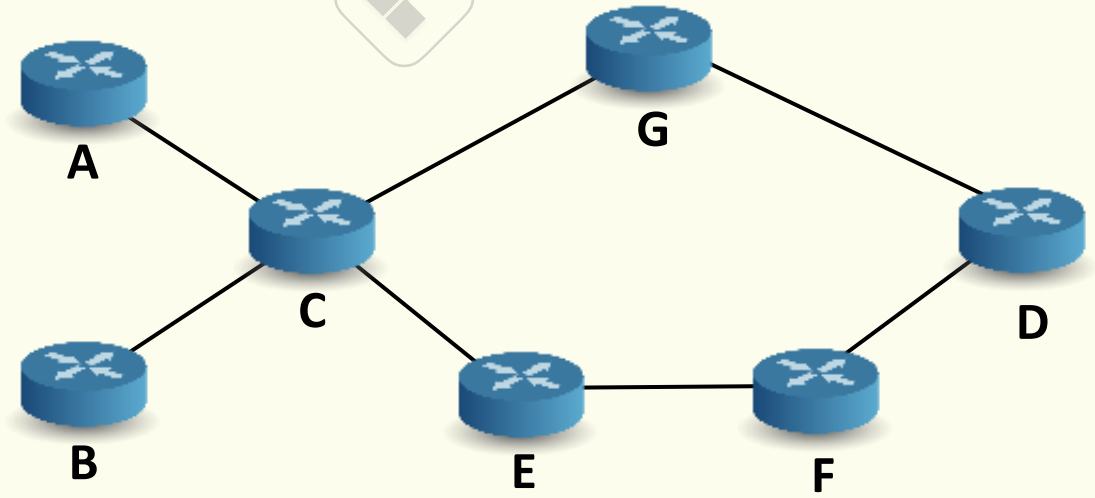
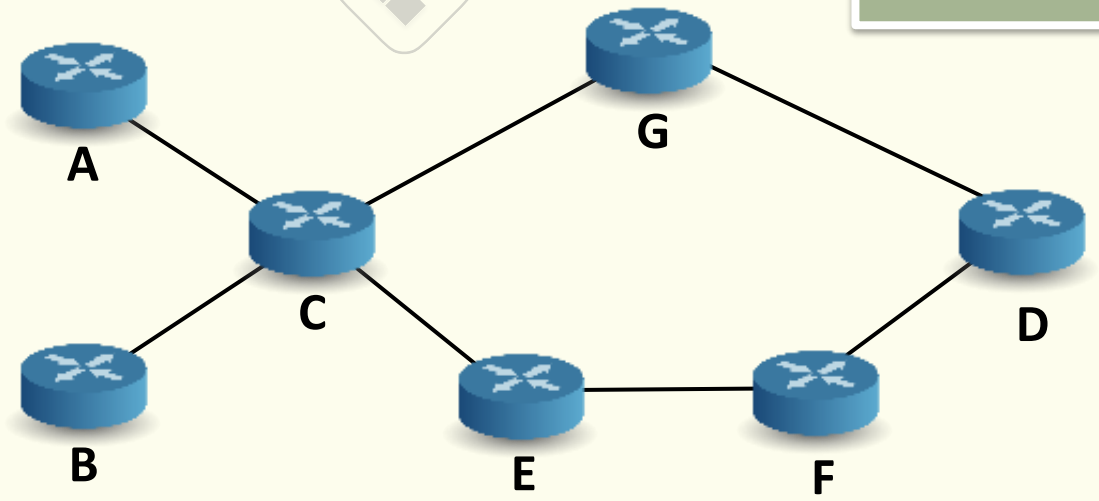


Traffic Engineering Database

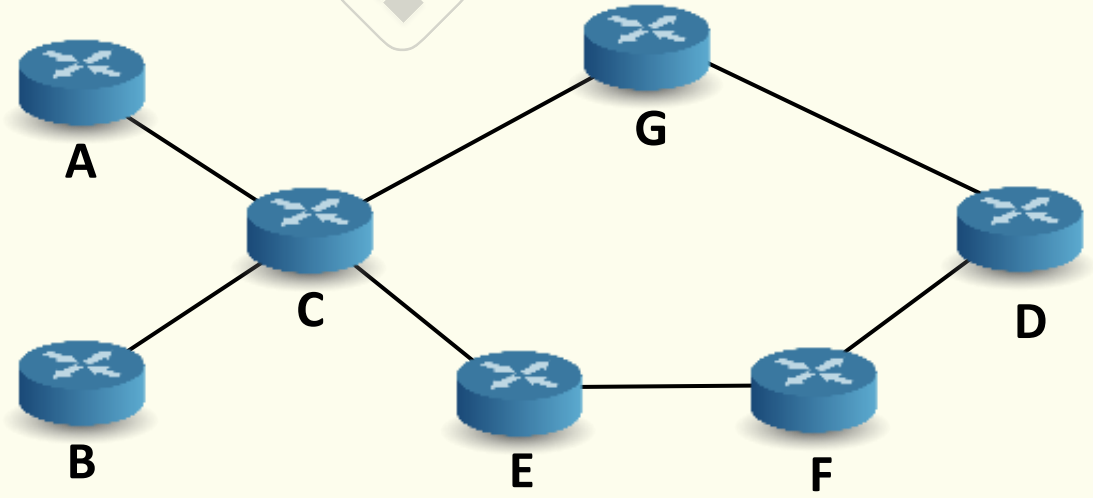
- **TE-related status change**
  - Change in the Unreserved Bandwidth: a router can be configured so that flooding is triggered only if the UB crosses certain thresholds

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

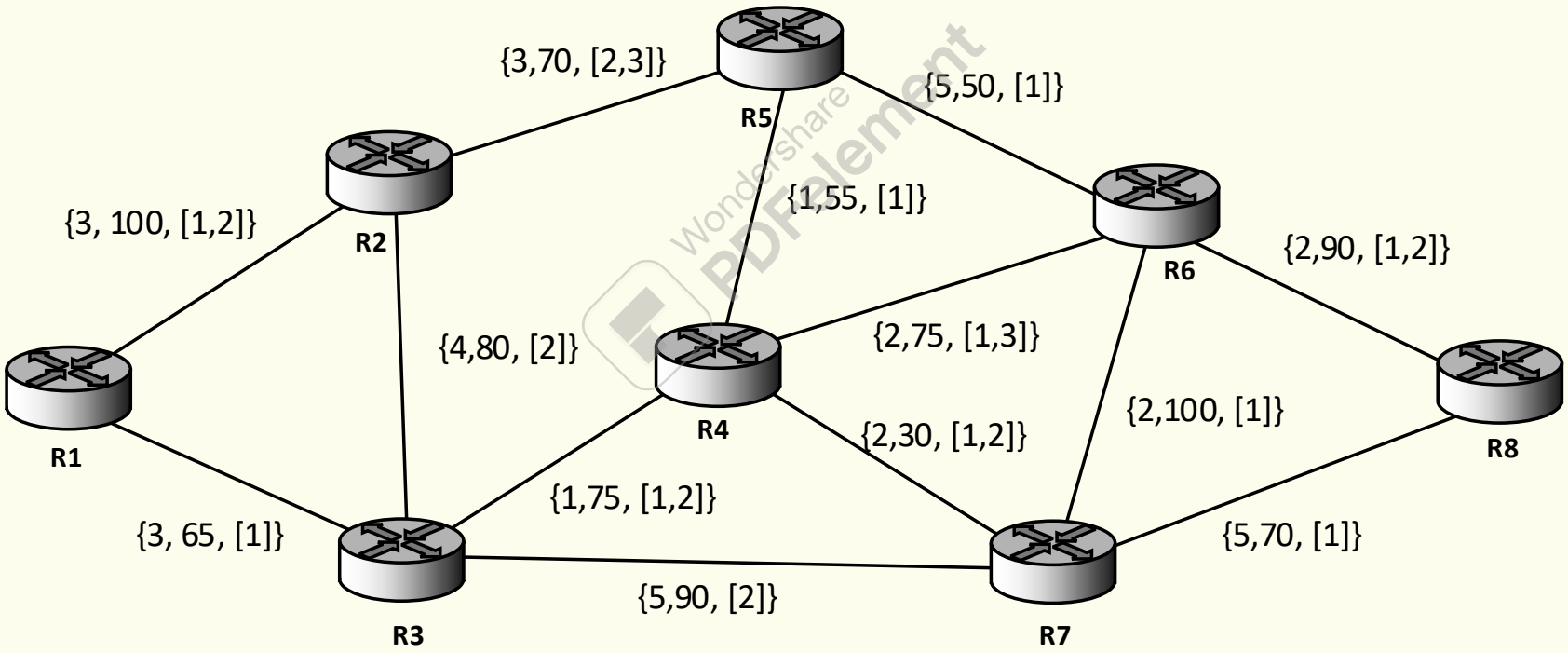
1. **Link characterization** (in a consistent manner) beyond the cost
   – Attributes
2. **Extended routing protocol**
   – To convey the enriched link characterization
3. **Constraint-based path computation algorithm**
   – Constrained Shortest Path First (CSPF)

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

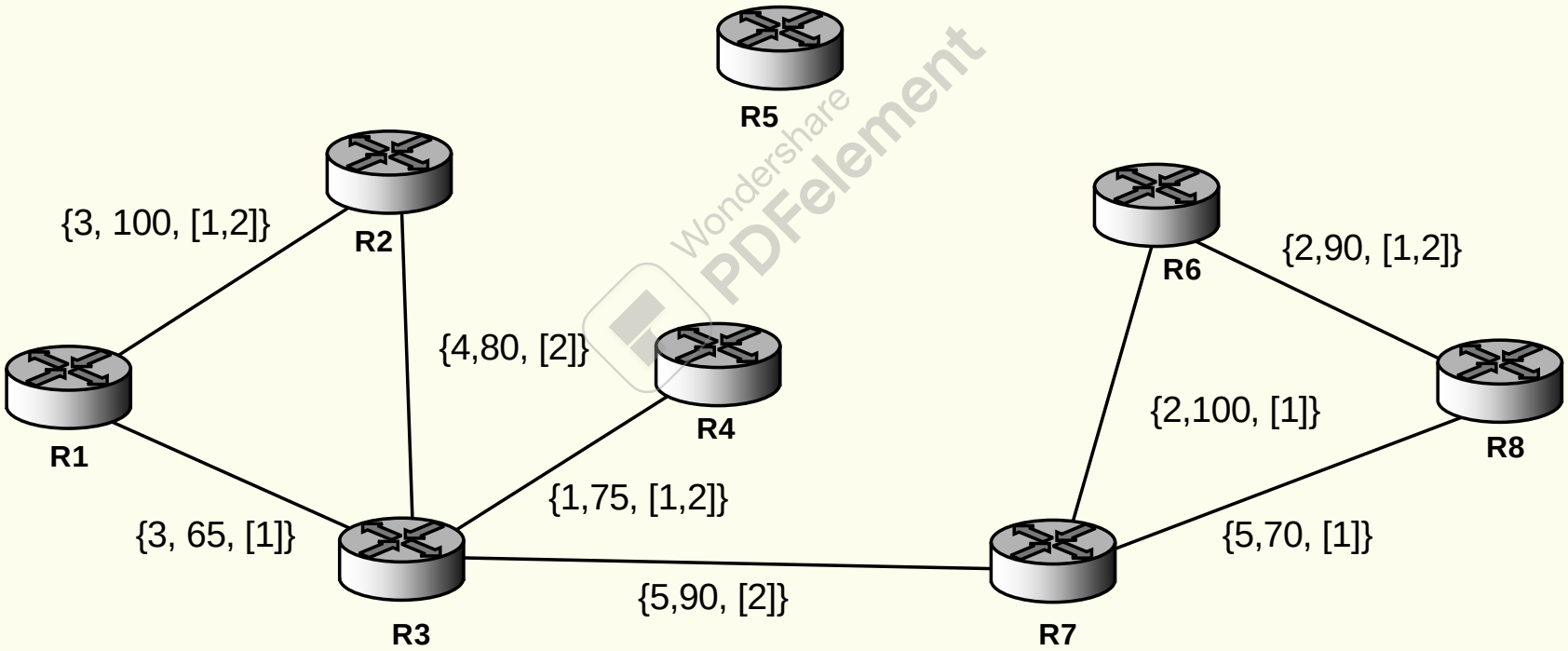
{Cost, Unreserved bandwidth, [Groups]}



LSP: R1→R8, 60Mb/s, exclude Group 3

CSPF example

{Cost, Unreserved bandwidth, [Groups]}



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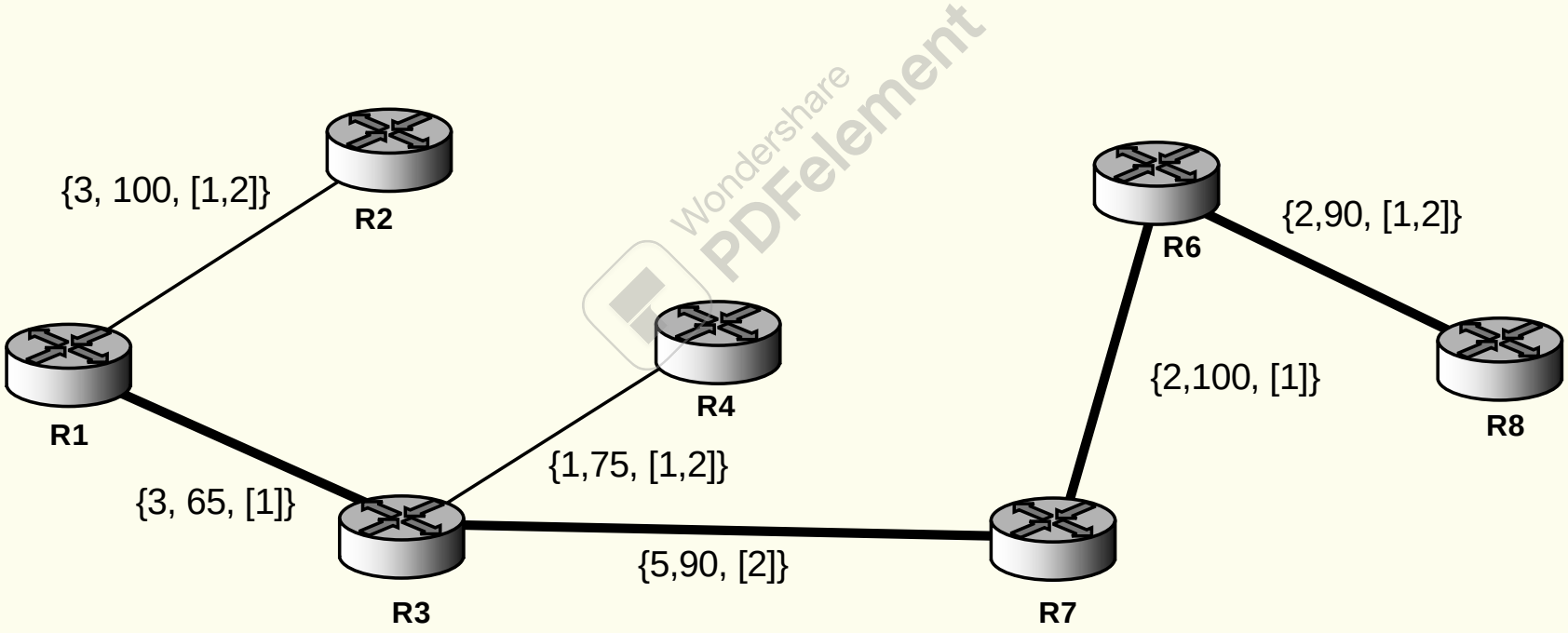
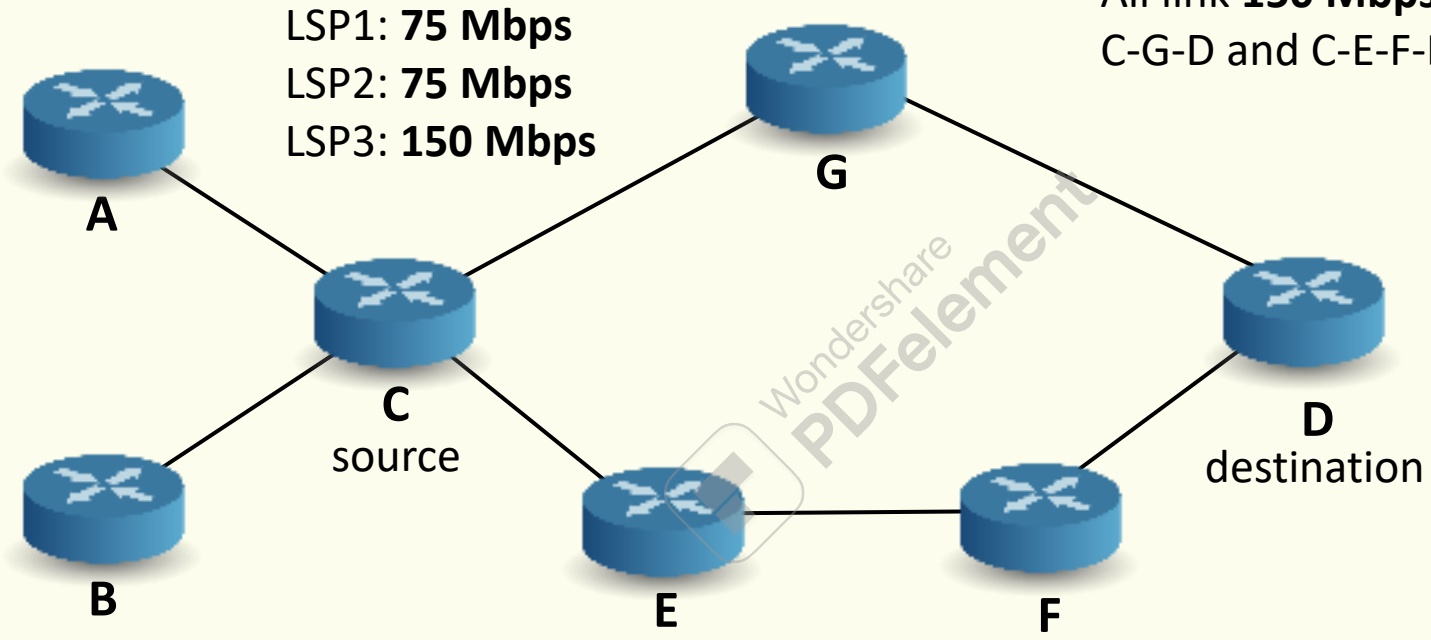
CSPF example

{Cost, Unreserved bandwidth, [Groups]}



LSP: R1→R8, 60Mb/s, exclude Group 3

Tie-breaking rules



Path-by-path solutions are sub-optimal for MPLS

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**