Computer Networks

Lecture on

Routing

Plan of This Lecture

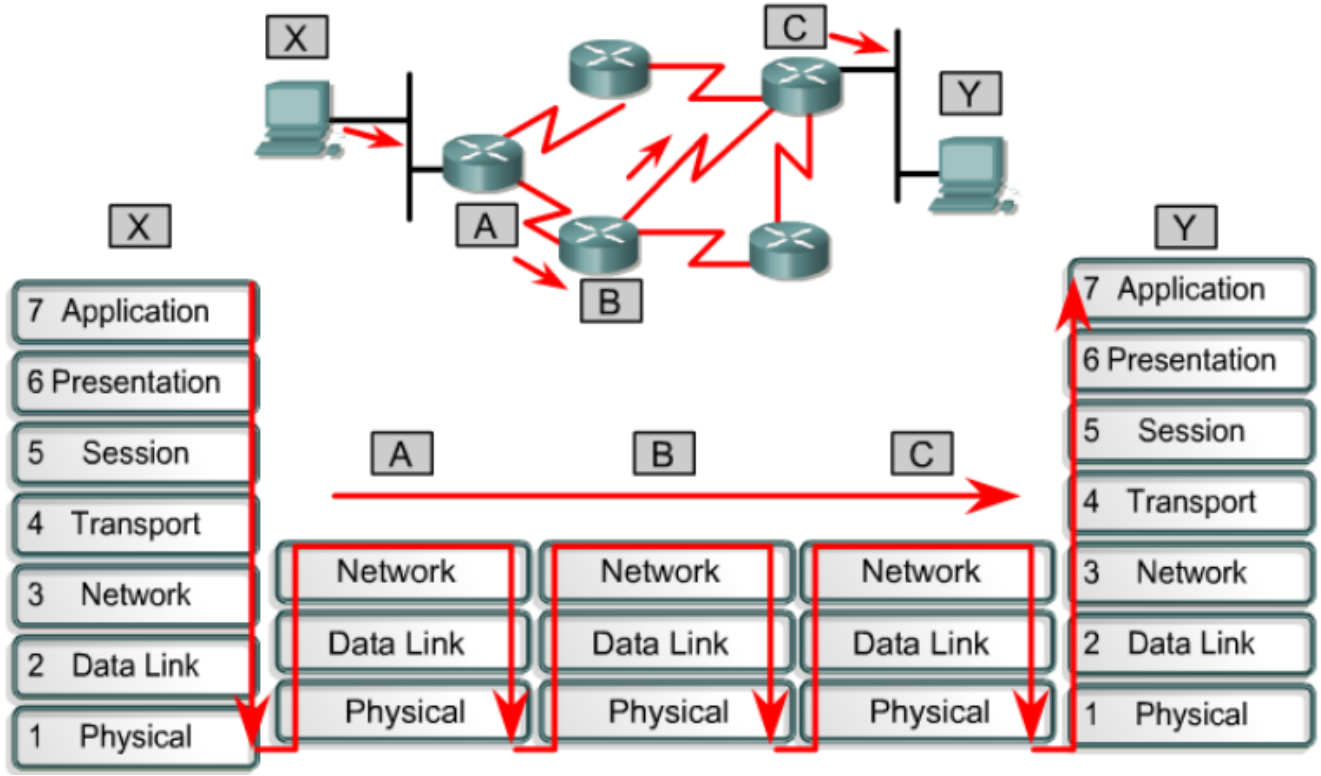
- Terminology
- Mechanisms
- Protocols

What is Routing?

Process of selecting an **optimal** data path through a network,
from sender to recipient

Metrics in routing

- Hop count
- Bandwidth
- Delay
- Load
- Reliability
- Cost
- ...



Different protocols use different metrics

Routing Taxonomies

static	vs.	dynamic
interior	vs.	exterior
distance-vector	vs.	link-state
classfull	vs.	classless
reactive	vs.	proactive
single-path	vs.	multipath
flat	vs.	hierarchic

Routing protocols route routed protocols

- routed (routable) protocols – forward data
- routing protocols – maintain routing tables

Static vs. Dynamic Routing

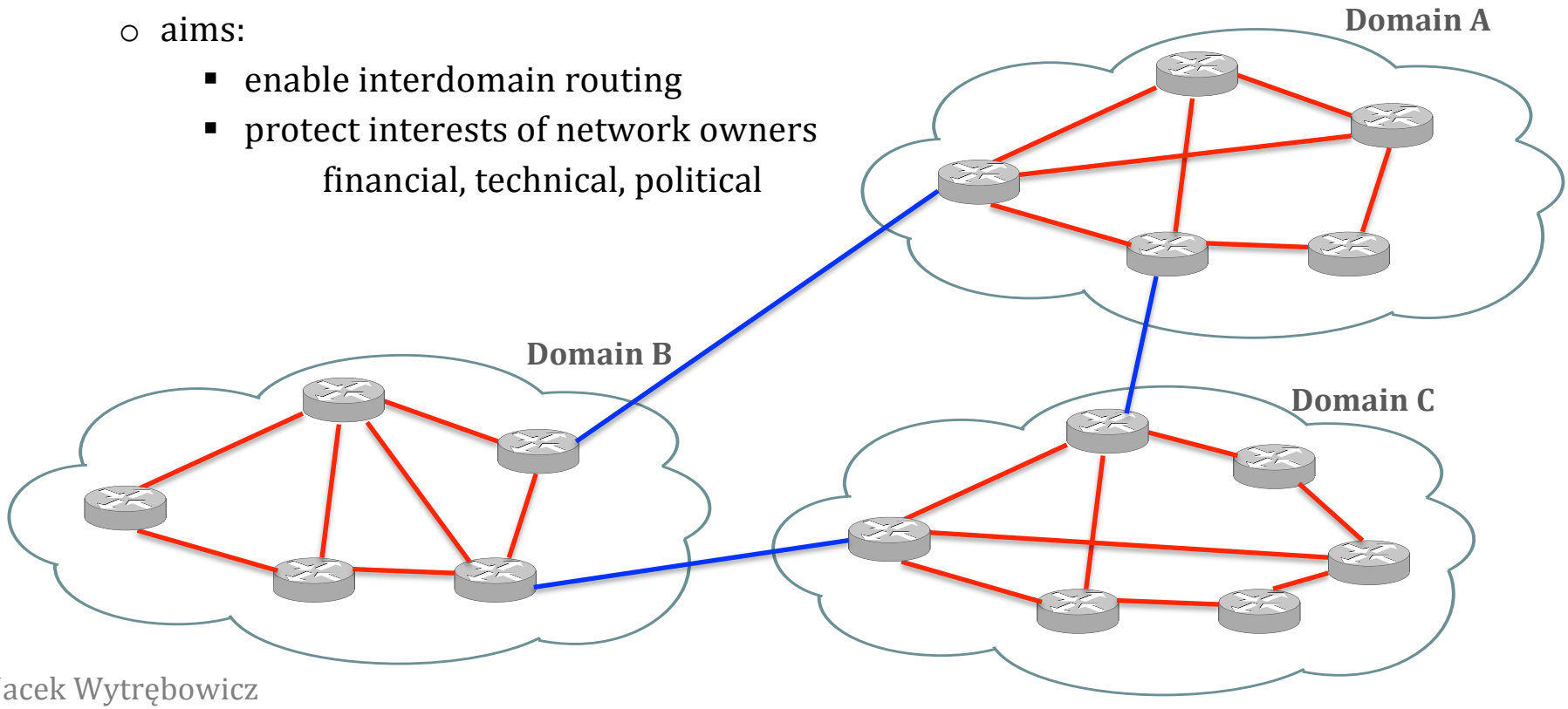
- Static
  - More predictable
  - Less load to the network
  - Can be used in a small network
    - highly secure network — e.g. a military one
    - to minimize energy consumption — e.g. in fixed sensor network

- Dynamic
  - Automatically adjust to changes in topology and load
  - Commonly used

IGP vs. EGP Routing

AS Autonomous system – administrative domain

- IGP Interior Gateway Protocols (Intradomain)
  - inside the AS
  - aim – efficient updating of routing tables
- EGP Exterior Gateway Protocols (Interdomain)
  - between AS's
  - aims:
    - enable interdomain routing
    - protect interests of network owners
      financial, technical, political



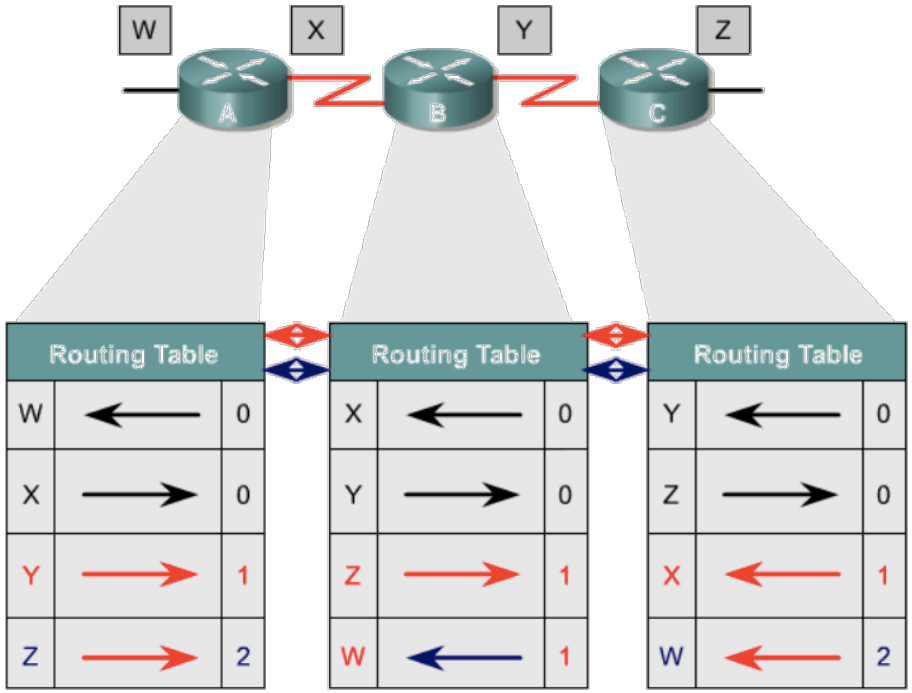
Distance-Vector vs. Link-State Protocols

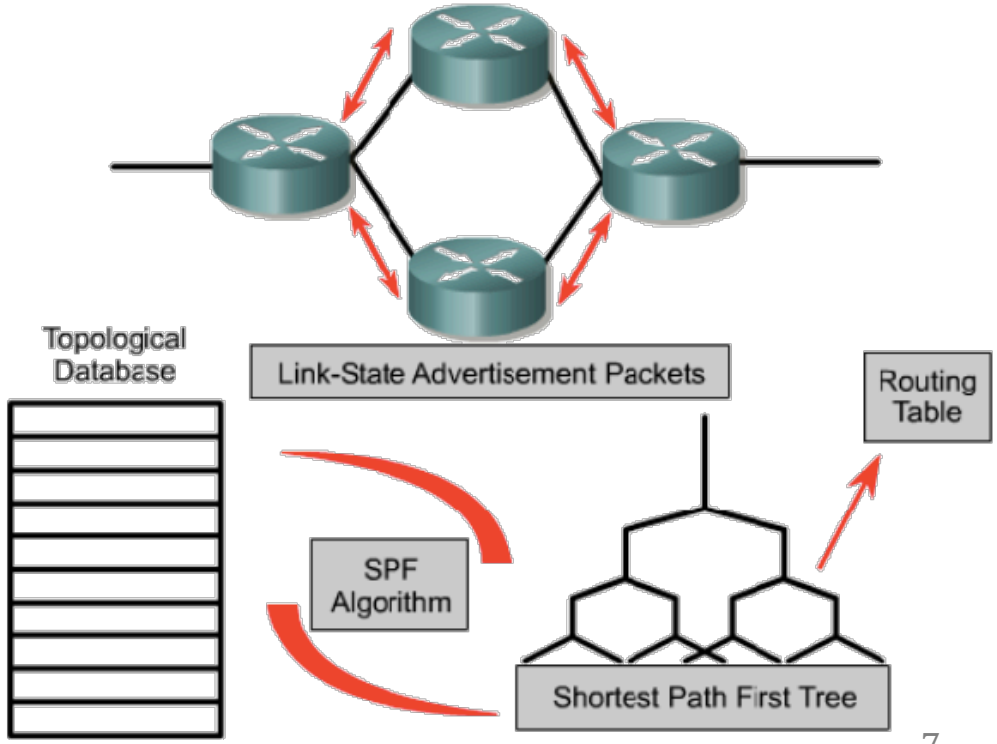
Distance-Vector

- about the neighbours
- to neighbours
- only distance
- ~ periodically
- simple
- slow-converging

Link-State

- about whole topology
- to all routers
- link state
- ~ after changes
- complex
- fast-converging





Reactive vs. Proactive

- Reactive – routers discover a path when it is needed
  - mobile ad hoc radio networks (MANETs) aka. wireless ad hoc networks (WANETs)
    e.g. Ad Hoc On-Demand Distance Vector (AODV) RFC 3561
- Proactive – routers discover all paths in advance
  - fixed cable and radio networks
- Hybrid – both proactive and reactive
  e.g. Hybrid Wireless Mesh Protocol IEEE 802.11s

Other Routing Types

Classfull vs. Classless

- Classfull – routers recognize subnet addresses by IPv4 address prefix
  - no more in use
- Classless – routers recognize subnet addresses by subnet mask value

Single-path vs. Multipath

- Multipath – routers discover two or more paths for each pair of end-points
  - for fast rerouting in case of failure
  - for higher transmission efficiency

Flat vs. Hierarchic

- Hierarchic routing is a must for big networks – provides scalability

Router Internals

Routers tasks

- Forwarding packets to the recipient
- Maintaining routing tables
- Informing other routers about changes in:
  - network topology
  - link states

Routing table content

- Source (routing protocol)
- Prefix (destination network, network mask)
- Outgoing interface / next hop
- Administrative distance
- Metrics

Routing table on PCs

`netstat -r` (Unix, MS Windows)

`route print` (MS Windows)

`nslookup`

`nettop -r`

`netstat -nr -f inet` – shows the existing routing table (IPv4 only)

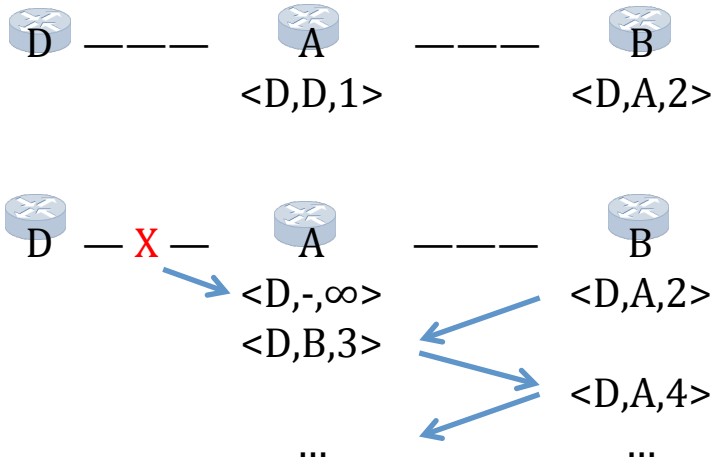
`route get HOSTNAME_OR_IP` – shows how a specific host will get routed

Desirable Features of Routing Protocols

- Quality of route optimization
- Simplicity
- Little overhead
- Robustness and stability, e.g.
  - Support for multipath routing
  - Support for different forward and backward paths
- Flexibility
- Fast convergence

Distance-Vector Slow-Convergence Problem

How a loop can arise:



Hold down – the simplest solution

- Do not use & advertise new alternative routes for two router-update cycles
- Widely adopted for small networks (RIP)
- Legitimate new routes are also delayed – disadvantage

Originator sequence number

- Vector contains a sequence number issued by the router directly connected to the subnet

Equal-Cost MultiPath Routing

Two or more routes of the same cost can be calculated and used by each router
i.e. more than 1 output interface is used to reach a given destination

- Most routing protocols support ECMP
  - administrator can enable and configure it
- Equal-cost ≠ equal-propagation-delay
- Round-robin
  - per-packet
    - better load-balancing between the paths
  - per-flow
    - TCP friendly
- Variants for radio networks
  - link-disjoint paths
  - node-disjoint paths

Most Popular Routing Protocols

- RIP Routing Information Protocol
- EIGRP Enhanced Interior Gateway Routing Protocol
- OSPF Open Shortest Path First
- IS-IS Intermediate System-to- Intermediate System
- BGP Border Gateway Protocol

There are numerous routing protocols for radio networks

	IGP	**EGP**
Distance-Vector	RIP	BGP
Hybrid	EIGRP	
Link-State	OSPF IS-IS	

All of them evolve

RIP

Main features

- Interior gateway protocol
- Open standard from IETF
- Distance-Vector
- Simple
- Metrics: hop count
- Broadcasts every ~30 s content of the routing table
  - Random delay eliminates risk of message synchronization
    i.e. all routers exchange tables at the same time
- Little max. hop count (15)
- One RIP message can carry up to 20 route entries – for IPv4 or IPv6 subnets
- Slow convergence (minutes)
- For little networks

EIGRP – Enhanced Interior Gateway Protocol

- Interior gateway protocol
- Once-proprietary Cisco protocol RFC 7868 in 2016
- Hybrid (distance-vector and link-state features)
- Max hop count: 224
- No risk of routing loops
- Flexible but complex 32-bit metrics
- Fast (because of backup routes)
- Mainly used in enterprise networks
- Metrics

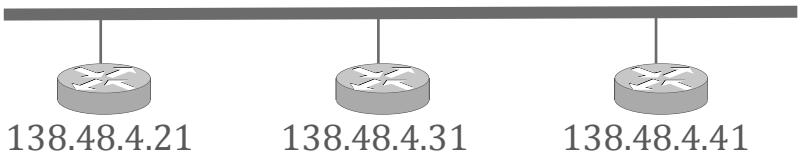
  [K1*bandwidth + (K2*bandwidth)/(256-load) + K3*delay] * [K5/reliability + K4]

  - Weighting constants K1-K5 (for tuning)
  - Default: K1=1, K2=0, K3=1, K4=0, K5=0
    thus: [Bandwidth, +Delay]

OSPF – Open Shortest Path First

Main features

- Interior gateway protocol from IETF
- Open standard
- Link-state
- Hierarchical architecture – areas
- Scalable
- Designated Routers on multi-access segments – DR represents its segment
  - minimize the number of routing messages
  - failure of the bus is processed correctly
- Areas allow for
  - summarization
  - containment of changes propagation
  - ⇒ scalability



- Frequently used in enterprise networks and in many ISP networks

OSPF – Basic Concepts

- Area
  - set of routers sharing the same knowledge
  - backbone area (#0)
  - non-backbone areas (#!0)
  - path between 2 non-backbone areas must pass by the backbone area
- Cost
  - feature of a link
- Adjacency database
  - contains information about all directly connected neighbours
- Topological database
  - detailed info about all routers and links in the area
  - summarized info about other areas and external networks – by distance vectors

OSPF – Operation

↓ Hello packets

- Adjacency database

↓ Initial Database Exchange

↓ Link state updates by flooding

- Topology database

↓ Dijkstra algorithm

- Shortest path first tree

↓ Best path selection

- Routing table

IS-IS Intermediate System-to-Intermediate System

Open standard from ISO

IS-IS & OSPF do the same

- Both establish a two level hierarchy among the areas
- Both have similar stability and convergence properties.
- Differ in many aspects, e.g.: tuning parameters, timeouts, data structure size & granularity
- Main differences:

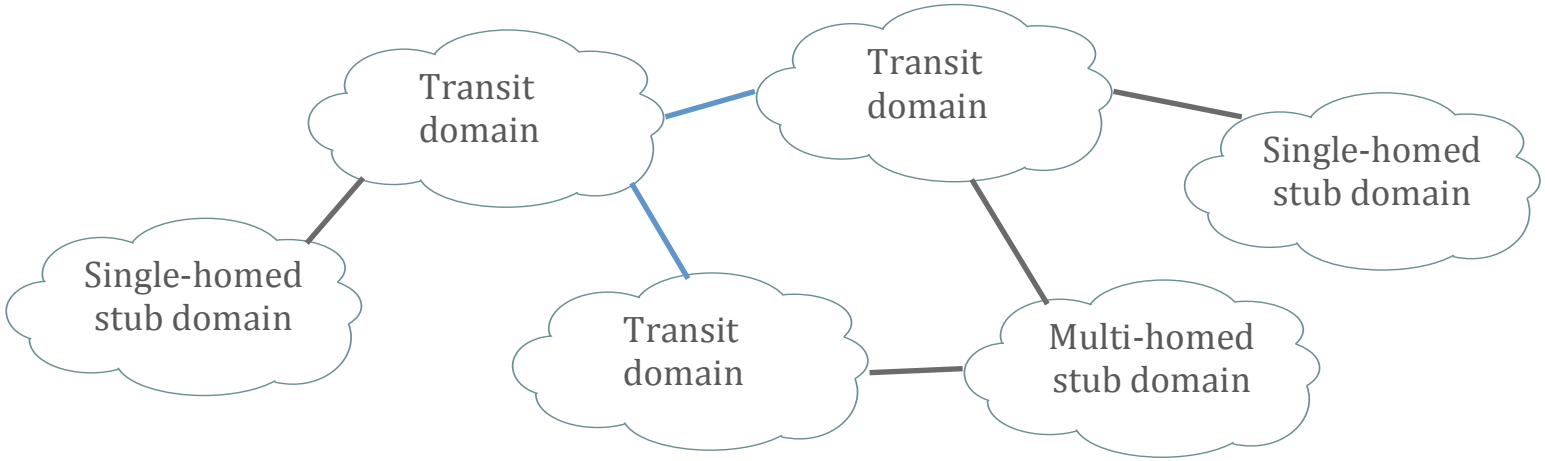
IS-IS	OSPF
Designed for any kind of networks • uses Type-Length-Value encoding	for IPv4 later IPv6
Works over data-link layer e.g. Ethernet • uses short messages • resistant against IP level attacks	over IP • can profit from IP fragmentation • can use virtual links
Area boundaries intersect on links	on routers

Large ISPs prefer IS-IS than OSPF

Autonomous Systems

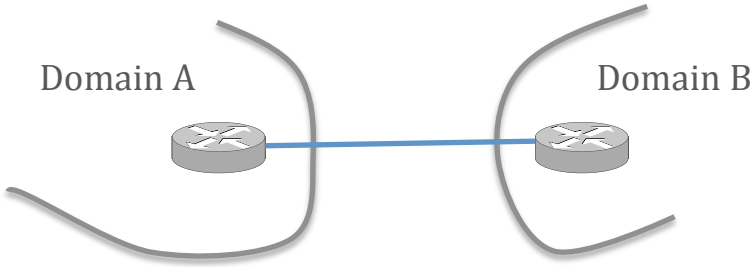
- Set of networks with a common administrative policy
- Seen from outside as a „black box”
- AS numbers are assigned by IANA & next by RIRs

Total number of active AS domains 63 520 April 2019
source: http://www.potaroo.net/tools/asn32/



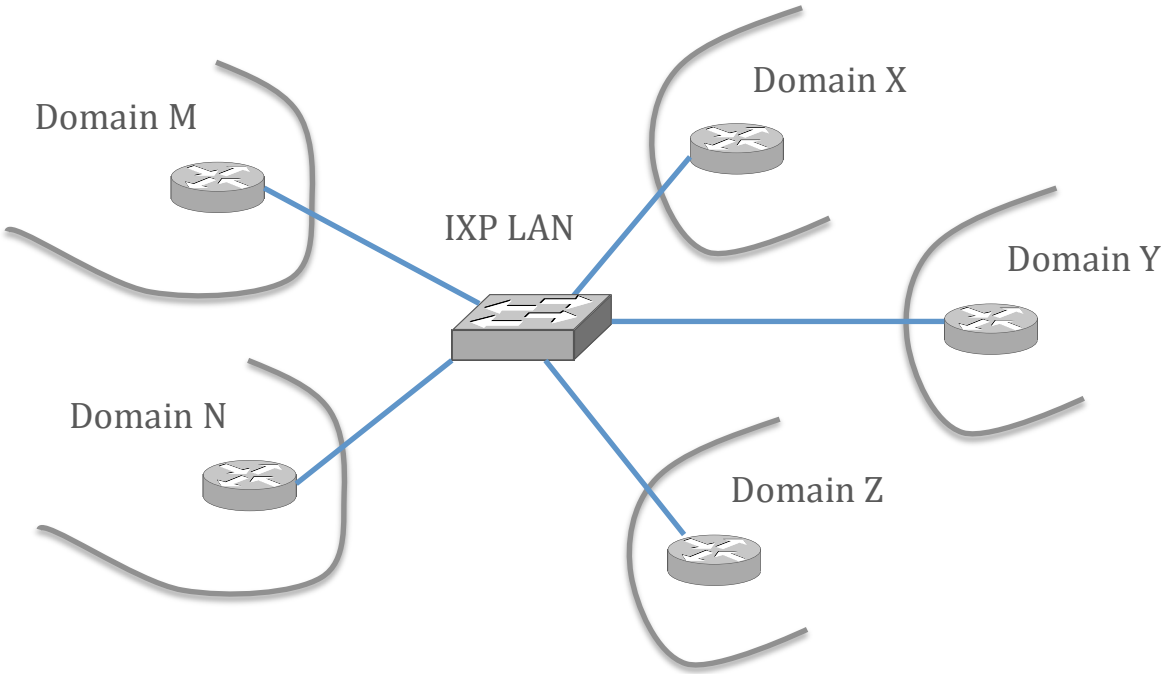
Domain Interconnections

- Private link



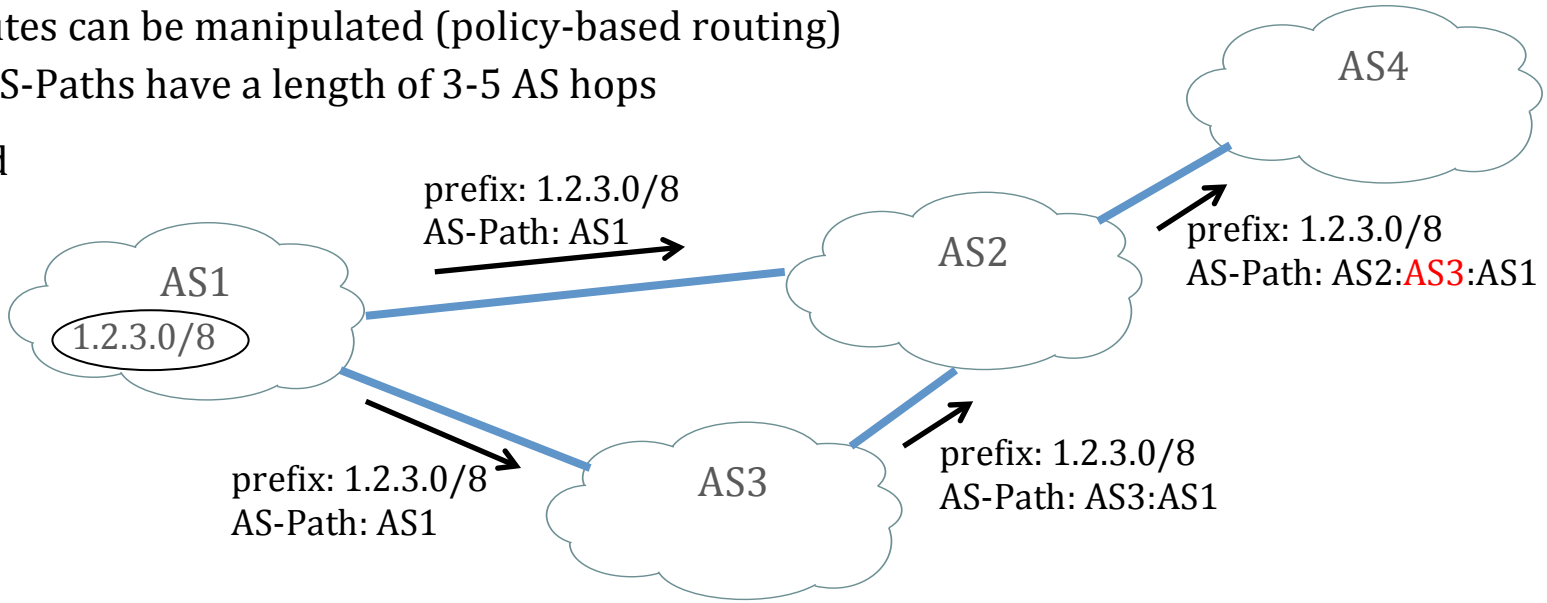
- Internet eXchange Point

  Datacentre hosting routers belonging to many domains – tens, hundreds



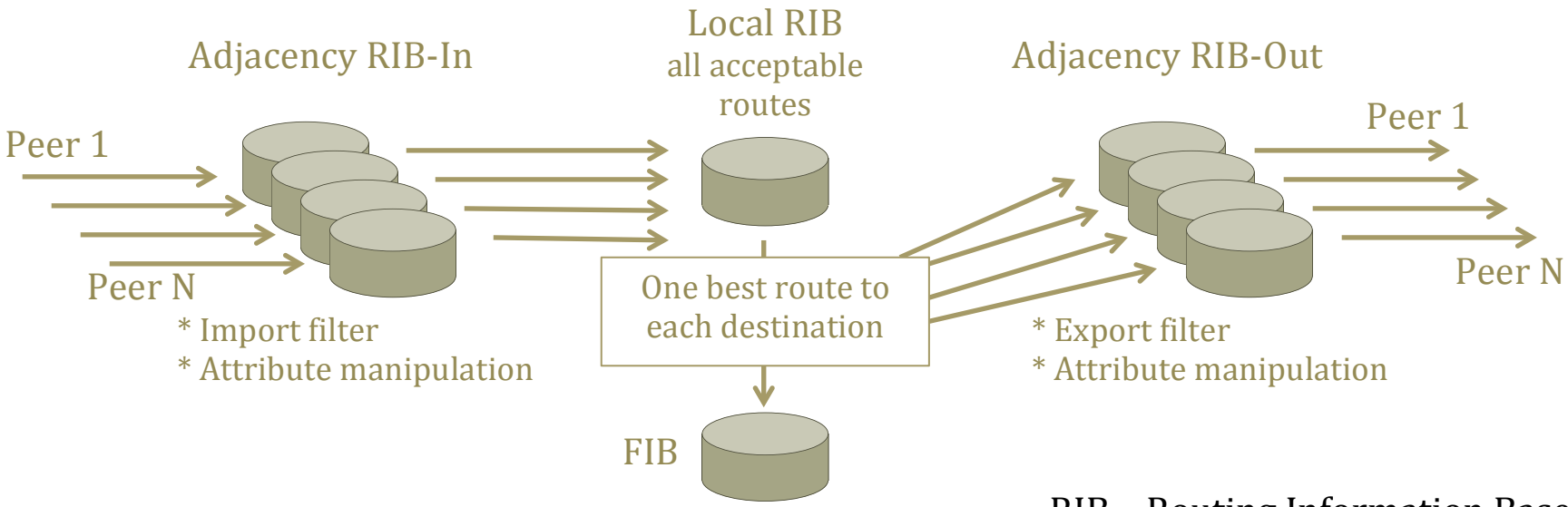
Border Gateway Protocol

- The sole Exterior Gateway Protocol used in the today's Internet
- Path-Vector
  - BGP path: a sequence of autonomous system numbers
  - Path attributes decide on route selection order
  - Attributes can be manipulated (policy-based routing)
  - Most AS-Paths have a length of 3-5 AS hops
- Policy-based



- Reduces transit traffic – according to defined policies

- Databases

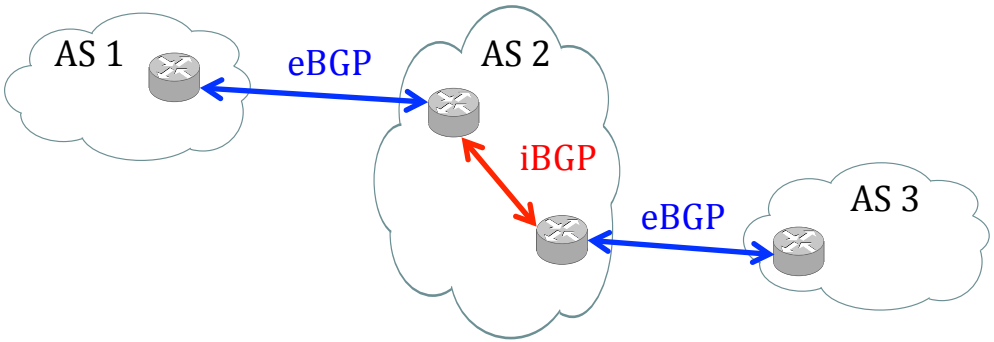


RIB – Routing Information Base

FIB – Forwarding Information Base

- Scalable
  - Incremental updates – it only announces the routes that have changed to its neighbours
- Update message
  - list of IP prefixes that are withdrawn
  - list of IP prefixes that are (re-)advertised
  - set of attributes (e.g. AS-Path) associated to the advertised prefixes
- Keep-alive message every 30 s

- Internal BGP carries
  - AS-paths and their attributes
  - only those allowed for transit



- Route aggregation (summarization)
  - With aggregation:
    - Neighbouring networks described with a single entry
    - Router knows details about it's directly connected networks
      the other routers – don't
  - Without aggregation:
    - Every network / subnetwork described with separate entries

- Route selection – complicated!
  - no metrics as in IGP

- Administration – complicated!
  - Route Policy Specification Language
    Several tools help to easily convert a RPSL policy into router commands
  - Inattentive configuration can lead to oscillation of routes

Summary

- What is Routing?
- Routing taxonomies
  - Static vs. dynamic routing
  - IGP vs. EGP routing
  - Distance-Vector vs. Link-State Protocols
  - Reactive vs. Proactive
  - Other routing types
- Router internals
  - Desirable features of routing protocols
  - Distance-Vector slow-convergence problem
  - Equal-cost multipath routing
  - Most popular routing protocols
- RIP
- EIGRP
- OSPF
  - OSPF – basic concepts
  - OSPF – operation
- IS-IS
- Autonomous Systems
  - Domain interconnections
- Border Gateway Protocol

Questions

1. What are the functionalities of routing protocols?
2. Give a short classification of routing protocols.
3. What metrics can be used by a routing protocol?
4. Characterize Distance-Vector and Link-State routing.
5. What kind of networks uses reactive routing protocols?
6. What metrics are possible in configuration of EIGRP?
7. What are the important features of the OSPF protocol?
8. How scalability is achieved by OSPF?
9. Why convergence of OSPF is much faster than convergence of RIP?
10. Why fast failover is possible in an OSPF cloud?
11. What are the main differences
12. Why RIP, OSPF and EIGRP are not suitable for radio ad hoc networks?
13. In which kind of networks are RIP, EIGRP, OSPF and IS-IS mainly used?
14. What is Internet eXchange Point?
15. What does it mean that BGP is a path-vector protocol?
16. What is the difference between EBGP and IBGP routers?
17. What databases does BGP router contain?