Routing in Computer Networks

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Resources

- **Book**: **Data.Communications.and.Networking.5th.Edition**
  - **Chapter 20: Unicast Routing**
- **https://computer.howstuffworks.com/routing-algorithm.htm**
- **https://www.computernetworkingnotes.com/ccna-study-guide/igp-egp-and-autonomous-system-explained.html**
- **https://www.gatevidyalay.com/distance-vector-routing-routing-algorithms/**

Lecture Objectives

- What routing is and why it is needed
- How routers learn, store, and update routes
- Differences between **static vs dynamic routing**
- Distance Vector, Link State, and Path Vector routing
- Shortest path algorithms (Dijkstra, Bellman-Ford)
- Routing tables, metrics, and administrative distance
- IPv4 and IPv6 routing
- Routing protocols: **RIPv2, OSPF, BGP**
- Forwarding and longest-prefix match
- Convergence and hierarchical routing

What Is Routing?

- **Routing** is the process of determining the optimal path for data packets to travel from a source device to a destination device across one or more interconnected networks.
- **The Three Core Router Functions**
  1. **Learn Routes:** A router must build its "map" of the network (**Statically** or **Dynamically**).
  2. **Store Routes:** The learned routes are kept in a **Routing Information Base (RIB)**, commonly called the **routing table**.
  3. **Forward Packets: This is the actual job. For each incoming packet, the router:**
     - **Checks the packet's destination IP address.**
     - **Looks up the best match in its routing table.**
     - **Switches the packet to the correct outbound interface and sends it to the next hop.**

Routing vs Forwarding

Aspect	Routing (Control Plane)	Forwarding (Data Plane)
Function	Path decision-making, builds the network map	Packet movement, executes delivery using the map
Core Task	Learn & calculate routes	Lookup destination & send packet to next hop
Speed	Slower (seconds), periodic updates	Real-time, per-packet (nanoseconds)
Complexity	Uses complex algorithms (OSPF, BGP)	Simple, hardware-optimized lookups
Table Involved	Builds/maintains Routing Table (RIB)	Consults Forwarding Table (FIB)
Key Focus	Optimal path selection, network convergence	Speed, throughput, low latency

Routing Metrics

- A **metric** is a quantitative value used by a routing protocol to determine the *best path* to a destination when multiple paths exist. Lower metric values generally indicate better paths.
- **Common metrics include:**

Metric	Definition & Use	Key Consideration
Hop Count	Number of routers a packet must pass through.	Simple but ignores bandwidth and speed.
Bandwidth	The capacity of a link.	Higher bandwidth = lower cost.
Delay	Time for a packet to traverse a link (latency).	Sum of interface delays along the path. Measured in microseconds.
Load	Current traffic usage of a link.	Dynamic and can cause frequent route changes if used.
Reliability	Error rate or uptime of a link.	Based on historical error counts
MTU	Maximum Transmission Unit, largest packet size the link supports.	Typically path with largest MTU is preferred.

Static Routing

- Static routing (non-adaptive routing) means the paths in the routing table are explicitly set by the administrator, specifying destination network, mask, and next hop or exit interface.
- These entries do not change automatically in response to topology changes; any modification requires manual reconfiguration.
- **Key characteristics**
  - **Manually configured routes.**
  - **Fixed, predictable paths; routing table entries stay the same until an administrator edits or removes them.**
  - **No routing updates exchanged between routers, so there is no routing protocol overhead.**
  - **Often used for small, stable networks.**

Static Routing: Advantages vs Disadvantages

Advantages	Disadvantages
No protocol overhead (CPU, memory, bandwidth)	No automatic adaptation to network failures
Full administrative control over paths	Manual configuration required on every router
Predictable traffic flow for troubleshooting	Doesn't scale, becomes unmanageable in large networks
More secure (no routing updates to attack)	Prone to human error in configuration
Simple to implement in small networks	No load balancing across multiple paths (without complex config)
No routing protocol knowledge needed	Time-consuming to maintain as network grows
Works on any router hardware	Single point of failure if not properly redundant

Dynamic Routing

- Dynamic routing is an adaptive routing method where routers communicate continuously to update their route knowledge, allowing traffic to be routed via multiple possible paths depending on current network conditions such as link failures, congestion, or topology changes.
- This ensures the network remains operational and efficient without manual intervention each time a change occurs.
- **Key characteristics**
  - **Automatic Updates.**
  - **Adaptability:** Dynamic routing protocols adjust routes in real-time, allowing networks to handle changes such as link failures or congestion without downtime.
  - **Scalability:** Dynamic routing efficiently supports large and complex networks by reducing manual configuration and management effort.
  - **Multiple Paths:** Unlike static routing, dynamic routing can maintain multiple paths to a destination.
  - **Load Balancing and Fault Tolerance.**

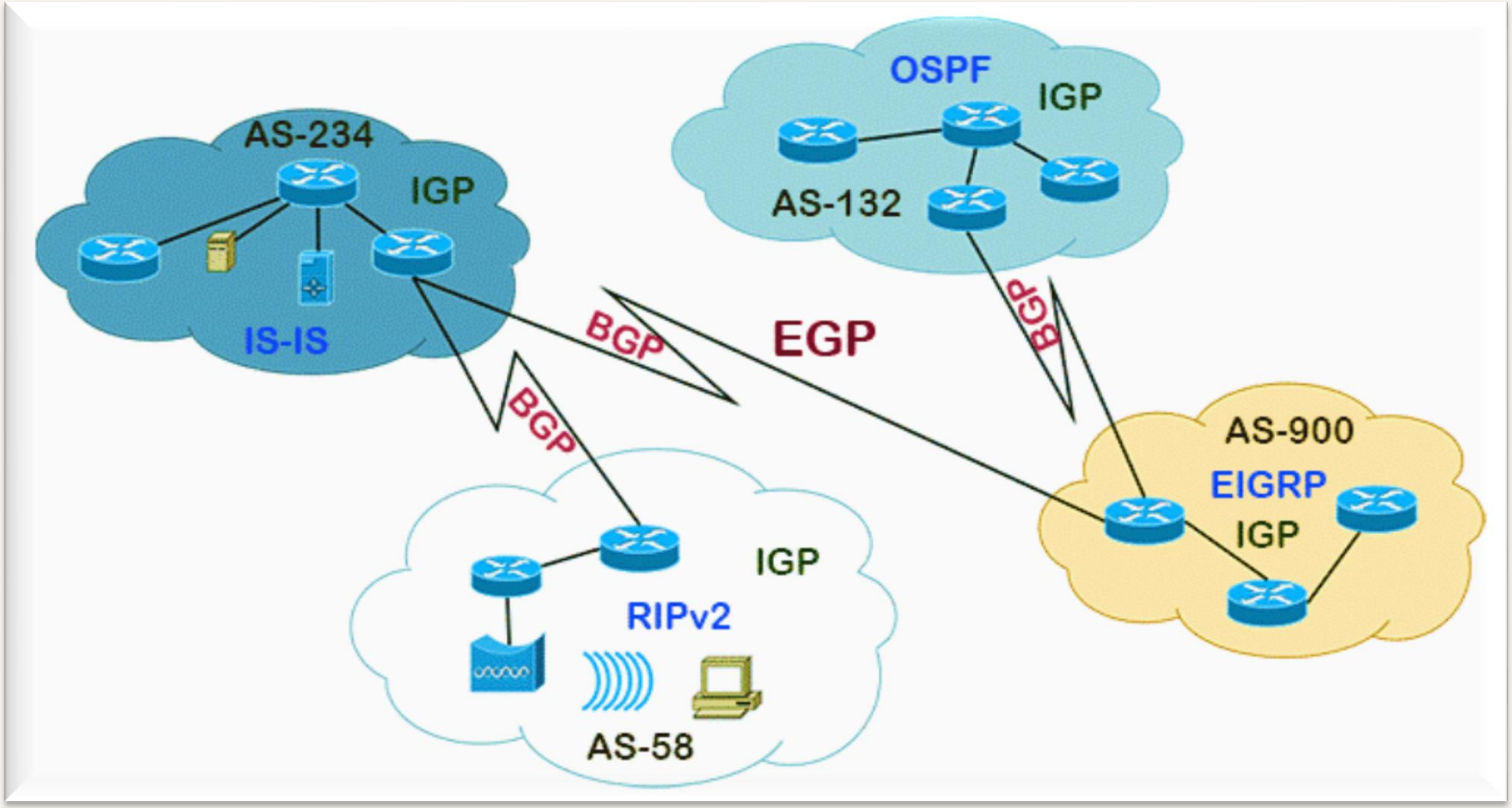
Dynamic Routing: Advantages vs Disadvantages

Advantages	Disadvantages
Automatic adaptation to topology changes	Protocol overhead uses CPU, memory, bandwidth
Scalable - works in large, complex networks	Less control over exact path selection
Load balancing across multiple equal paths	Security vulnerabilities (protocol attacks, route poisoning)
Automated failover when links fail	Complex configuration requires protocol knowledge
Reduces human error through automation	Unpredictable convergence during network changes
Self-documenting (network discovers itself)	Route flapping can cause instability (continuous changes in routing tables)
Supports hierarchical designs (areas, AS)	Additional configuration for security/optimization

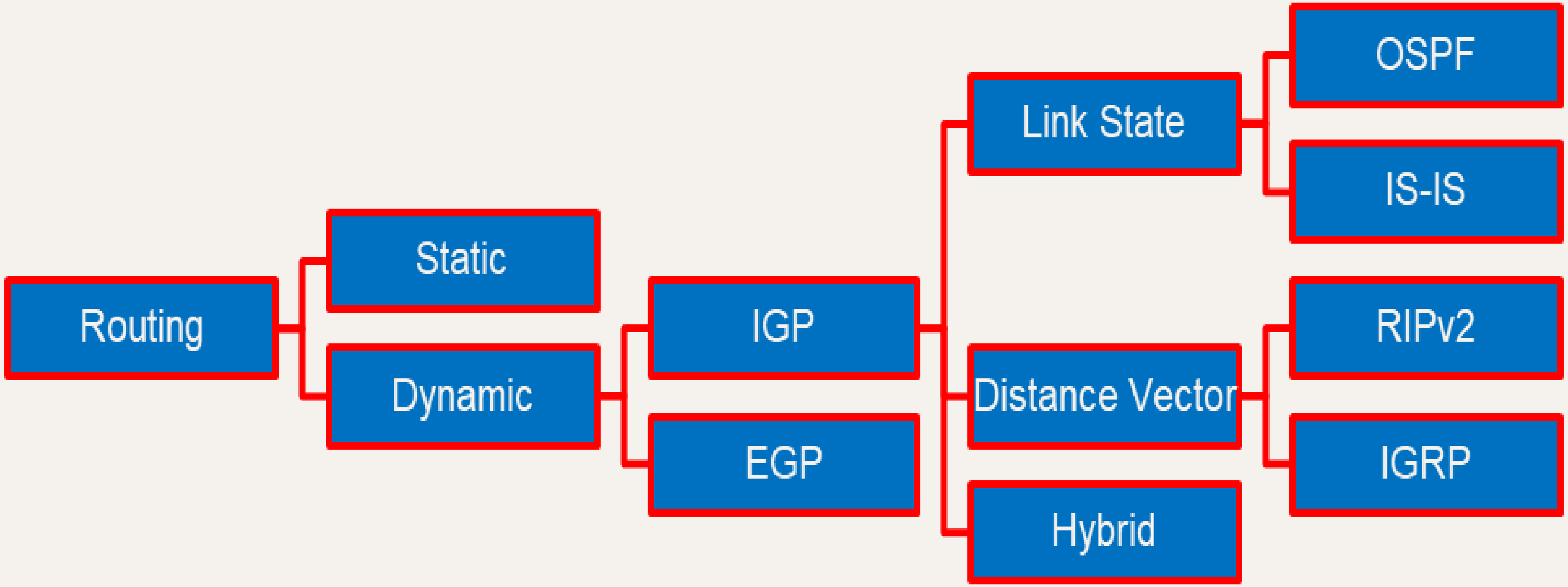
Dynamic Routing Protocols

- **By Scope**
  1. **IGP (Interior Gateway Protocol):** is used for routing data within a single autonomous system (AS), which typically means inside an organization or a single administrative domain. It manages how routers in the same AS communicate and determine paths. Examples include OSPF, RIP, EIGRP, and IS-IS.
  2. **EGP (Exterior Gateway Protocol):** is used for routing data between different autonomous systems. It is employed by ISPs or organizations to route traffic across the internet or between separate networks. The primary EGP in use today is the Border Gateway Protocol (BGP).
- **An Autonomous System (AS)** is a group of networks that is governed and controlled by a single administrative entity. For example, a network created by a single company, organization, corporation, or ISP is a single AS.

Dynamic Routing Protocols (Cont.)



Classification of routing protocols



Distance Vector Routing

- **Distance-vector routing** is a type of distributed routing protocol. Routers using this protocol regularly **share information with their directly connected neighbors** to learn the distance to different destinations. When a router gets this information, **it adds its own distance to the advertised routes and updates its routing table**.
- The term “**distance-vector**” refers to how the routing protocol calculates and communicates route information:
  - **Distance** refers to the metric for determining the shortest path, typically measured in hop count.
  - **Vector** represents the direction (or next-hop router) the packet should take.

Distance Vector Routing (Cont.)

- **Key Characteristics**
  - **Periodic Updates:** Routers regularly send updates, such as every **30 seconds** in **routing information protocol (RIP)**, to their neighbors. These updates share distance metrics and help maintain consistent routing information across the network.
  - **Hop Count as a Metric:** This protocol uses **hop count**, the number of routers a data packet passes through, to find the **shortest path**. However, it **doesn't account for factors like link speed or network congestion**.
  - **Routing by Rumor:** Distance-vector routing relies on exchanging information with neighboring routers, giving each router an **indirect view of the entire network**. **This method is often called "routing by rumor".**
  - **Uses Bellman-Ford algorithm**

How Distance-Vector Routing Works

- **Routing Table Updates.** Each router keeps a routing table listing:
  - **Known destinations**
  - **The next-hop router to reach those destinations**
  - **The distance (hop count) to each destination**
- **The routing process follows these steps:**
  1. **Each router sends its routing table to directly connected neighbors at fixed intervals.**
  2. **Routers update their tables based on the shortest-path information they receive. If a neighbor advertises a better (shorter) route to a destination, the router will update its table accordingly.**

Advantages and Disadvantages of Distance-Vector Routing

- **Advantages**
  - **Simple Configuration:** Distance-vector protocols are straightforward to implement, making them ideal for small networks or non-complex setups.
  - **Efficient for Stable Topologies:** They work well in networks with consistent, infrequent changes.
  - **Minimal Processing Overhead:** Routers require fewer resources to run, as only neighboring information is exchanged.
- **Disadvantages**
  - **Slower Convergence:** Distance-vector protocols take longer to converge compared to link-state alternatives, increasing the potential risk of temporary routing loops.
  - **Scalability Challenges:** Hop count metrics limit these protocols in large, dynamic networks.
  - **Higher Bandwidth Use:** Periodic updates consume significant network bandwidth, especially in scenarios with frequent topology changes.

Link State Routing

- Link-state routing is a type of distributed routing protocol. Routers using this protocol share information about their directly connected links with all routers in the network. When routers receive this information, they build a complete, identical map of the network topology. Each router then independently calculates the shortest path to every destination using this map.
- The term "link-state" refers to how the routing protocol calculates and communicates route information:
  - Link refers to the router's direct network connections (interfaces and neighbors)
  - State represents the condition, cost, and attributes of each link (up/down, bandwidth, delay, etc.)

Link State Routing (Cont.)

- **Key Characteristics**
  - **Topology Database (LSDB):** Every router maintains an identical Link State Database containing the **complete network map with all routers, links, and their states**.
  - **Shortest Path Calculation:** Each router runs the **Dijkstra's Shortest Path First (SPF) algorithm independently on the LSDB** to compute the optimal routes to all destinations.
  - **Event-Triggered Updates:** **Instead of periodic updates**, **routers send Link State Advertisements (LSAs) only when a network change occurs (link up/down, cost change)**. **This makes the protocol more bandwidth-efficient**.
  - **Hierarchical Design:** Link-state protocols support dividing large networks into areas or levels to improve scalability and reduce processing overhead.
  - **Fast Convergence:** **Because every router has the complete network map**, **changes propagate quickly and routing tables can be recalculated immediately**.

How Link State Routing Works

- **The Link State Database (LSDB): Each router maintains a database containing:**
  - **All routers in the network**
  - **All links between routers**
  - **The state (up/down) and cost of each link**
- **The routing process follows these steps:**
  1. **Neighbor Discovery:** Each router identifies its directly connected neighbors using Hello packets.
  2. **Link State Advertisement (LSA):** Routers create LSAs describing their local links (connected networks, neighbors, link costs) and flood these to all routers in the network.
  3. **Database Synchronization:** All routers exchange LSAs until every router has the same complete LSDB.

How Link State Routing Works

4. **Shortest Path Calculation:** Each router independently runs the Dijkstra algorithm on the LSDB to build a shortest-path tree with itself as the root.
5. **Routing Table Construction:** From the shortest-path tree, each router builds its routing table with:
   - **Destination networks**
   - **The next-hop router for each destination**
   - **The total cost to reach each destination**

Advantages and Disadvantages of Link State Routing

- **Advantages**
  - **Fast Convergence.**
    - Routers can rapidly detect link failures.
    - Only changes (LSAs) are flooded, not the entire routing table.
  - **More Accurate View of the Network**
    - Each router maintains a complete topology map.
    - Decisions are made using precise information.
  - **Scalable for Medium to Large Networks**
    - Large networks can be divided into manageable regions.
  - **Efficient Use of Bandwidth**
    - Only link-state changes are flooded.
    - No periodic full-table broadcasts.
  - **Loop-Free Path Selection**
    - SPF (Shortest Path First) algorithm guarantees loop-free routes.

Advantages and Disadvantages of Link State Routing

❑ Disadvantages

- **Higher CPU and Memory Requirements**
  - Routers must store: LSDB (topology map) and Routing tables.
  - Running Dijkstra's algorithm consumes CPU resources.
- **More Memory for Topology Databases**
  - Each router must store complete network topology, not just neighbor routes.
  - LSDB grows as network grows.
  - Larger networks = more memory usage.
- **Initial Setup Takes Time**
  - Before routing starts, each router must: Discover neighbors, Exchange LSAs, Build LSDB, Run Dijkstra.
  - Distance vector protocols start working faster but converge slower.

Advantages and Disadvantages of Link State Routing

- **Not Ideal for Very Small Networks**
  - Simple static or distance vector routing is enough.
  - Link State adds unnecessary complexity for tiny networks.
- **Initial Flooding Overhead:**
  - When a router first joins the network or after a failure, there's significant flooding of LSAs as the database synchronizes

Any Questions