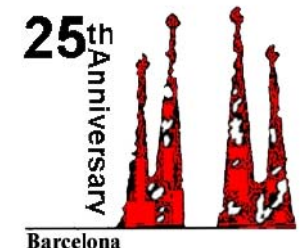


Evolution of unicast routing protocols in data networks

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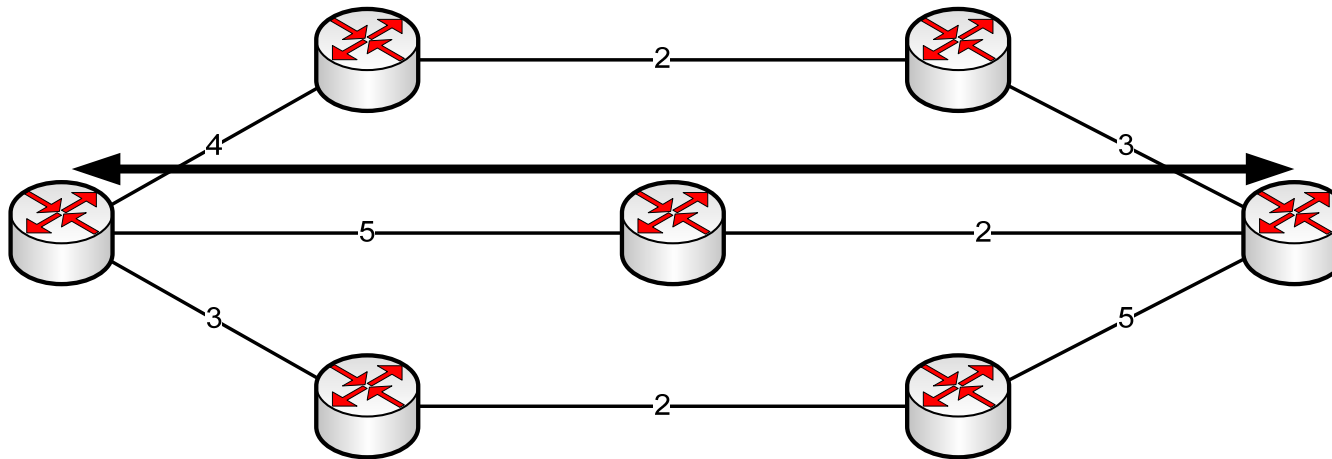




History of unicast routing

- **Late 1950s – Early 1960s take place the first routing algorithms that find the shortest path between two points**
 - Bellman-Ford algorithm
 - Dijkstra algorithm
- **1969 → ARPANET uses Bellman-Ford as its routing algorithm
→ Today's RIP**
 - In 1980 it adopts OSPF as its routing protocol, based on Dijkstra's algorithm
- **Shortest Path Routing evolution can be splitted in two branches**
 - Disjoint Shortest Path Routing
 - Multipath Routing
- **Simultaneously with SP Routing, some studies about flow optimization took place → Optimal Routing**
 - Fratta (1973) introduced the “Flow Desviation Method” for ARPANET

History of unicast routing



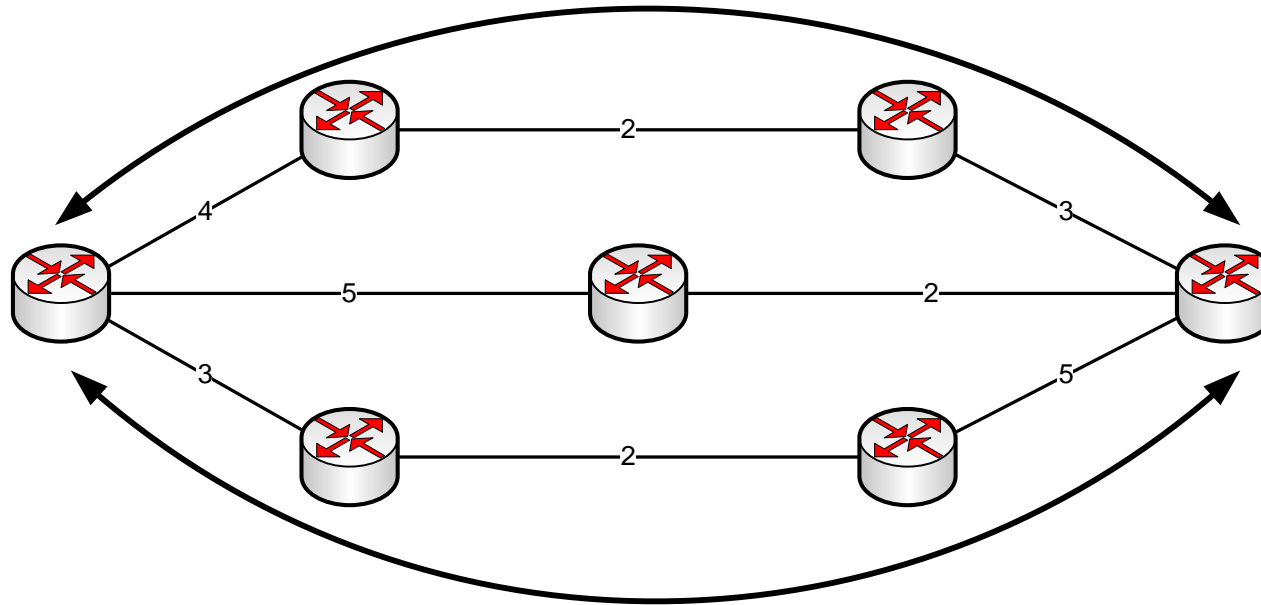
- The Shortest Path is found with static metrics
 - Bellman-Ford is based on the number of hops between source and destination (RIP)
 - Dijkstra is based on the cost of a link (OSPF, IS-IS)
 - EIGRP is based on DUAL algorithm and rely on bandwidth and delay by defaults of the links.
- If there's a bottleneck in the SP, the algorithm does not change the path to another one.



SP routing: Disjoint path Routing

- Disjoint Path Routing provides a pair of minimum total length independent paths to increase the reliability in communications.
- Some proposals try to find “k” independent paths but they turn into an NP-Complete algorithm
- Some important studies are from:
 - Ogier
 - Aumenting path technique
 - Sidhu
 - Message distribution algorithm to mark the disjoint paths
 - Orda
 - Try to find QoS disjoint paths → NP-Complete

SP routing: Disjoint path Routing



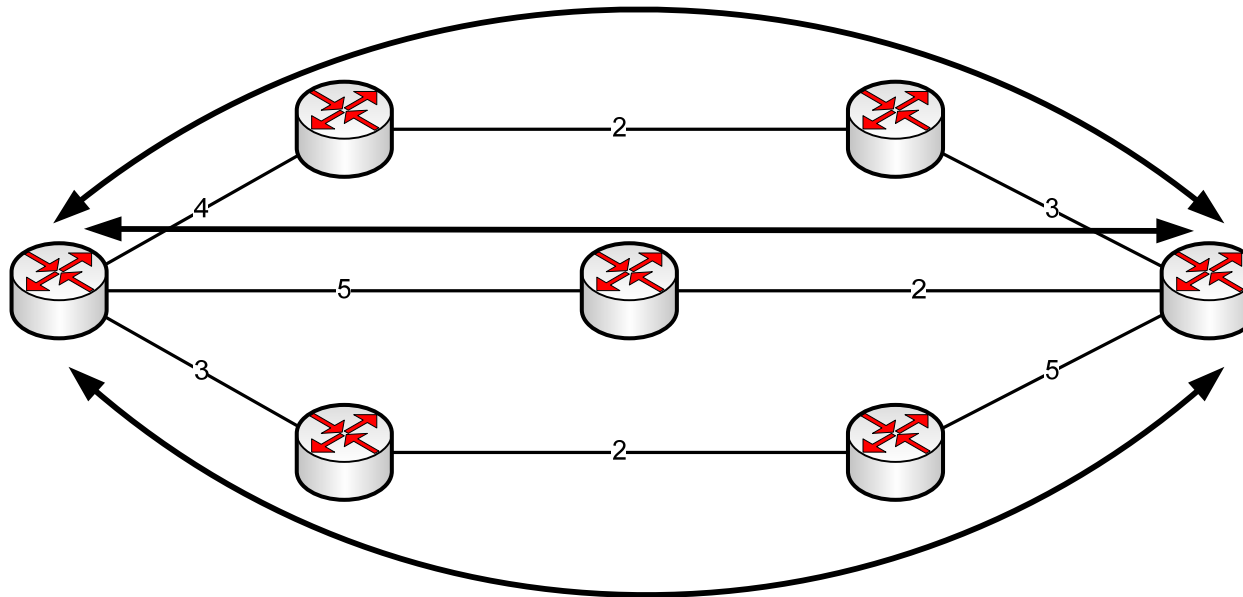
- The disjoint path routing looks for two independent paths
 - With the augmenting path, the SP could not be one of these paths
 - Sometimes it is not possible to find disjoint paths in a network



SP Routing: Multipath Routing

- Multipath routing finds “k” best paths for a destination.
- The information is load-balanced among these paths → Average network delay is reduced
- Important work made by Garcia Luna:
 - He uses LFI (Loop-Free Invariants) to find “k” loop-free paths with MDVA, Multipath Distance Vector Algorithm (2001)
 - Based on Bellman-Ford algorithm and DUAL
 - Prior to MDVA, Garcia Luna concluded some other multipath algorithms
 - DASM (1998),MDPA (1999), MPATH (2000)

SP Routing: Multipath Routing



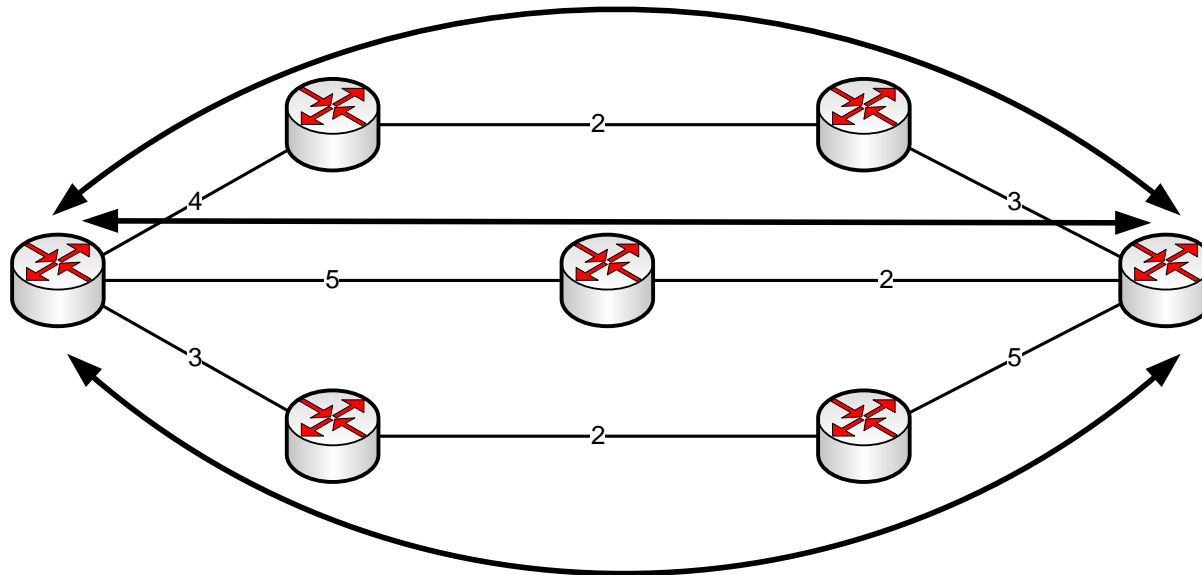
- The load-balancing could be made in different ways
 - Round Robin Load Balancing → Each packet takes a path to the destination
 - Per Flow Load Balancing → Each TCP flow takes a source-destination path
 - Important Studies of F. Kelly.



Optimal Routing

- Optimal routing optimizes the average global delay of a network instead of finding the shortest path to a destination.
- Efficient way of designing a network
- Not adequate for real networks → Slow convergence and dependence on global parameters, sometimes difficult to know a priori.
- Important studies of Gallager (1977) → Proposes the first distributed optimal routing algorithm.
- Recent studies simplifies Gallager formulation for real-networks
 - Aproximation for Bellman-Ford Networks → **NEAR-OPT (1999)**
 - It uses Diffusing computation
 - Aproximation for Dijkstra networks → **MPDA (1999)**
 - Aproximation made with the use of LFI (Loop-Free Invariants)

Optimal Routing



- Optimal routing find the best combination of paths that minimizes the general delay of the network

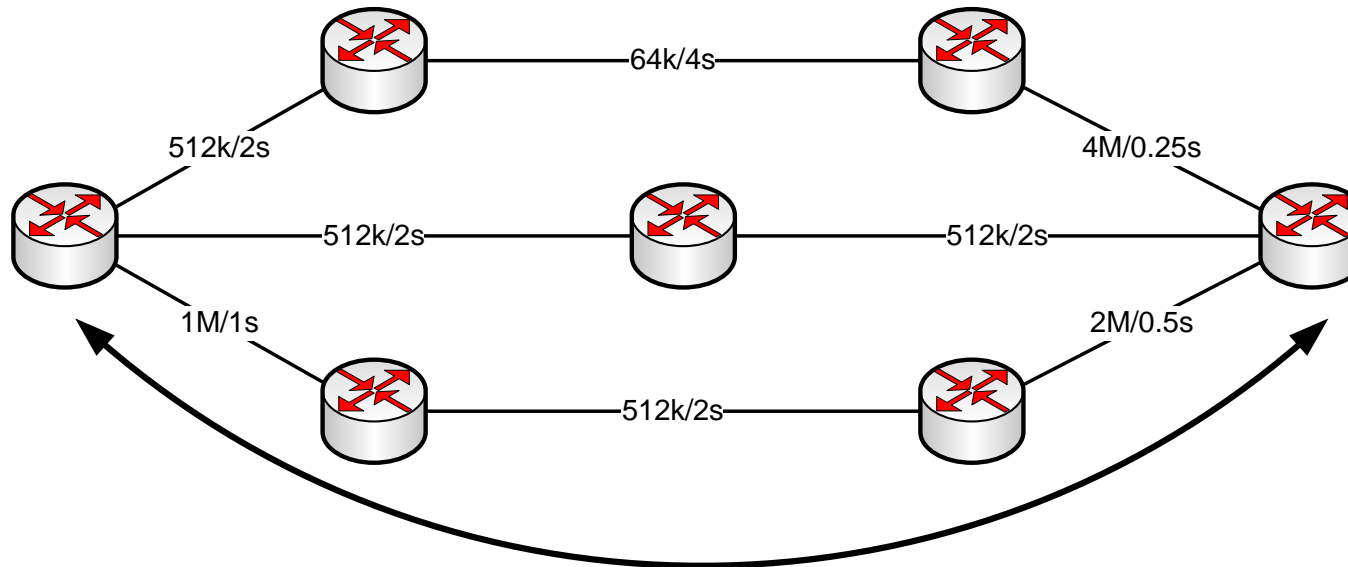
$$D_T = \sum_{i,k} D_{ik} (f_{ik})$$



Constrained Routing

- Adds QoS constraints to routing calculations
 - Link optimization → concave metrics (BW)
 - WSP, SWP, MRBHP routing problems
 - Path optimization → additive and multiplicative metrics (delay, reliability)
 - Evolve from the optimal routing but they only work with one path instead of the whole network.
 - Multi Constrained Routing → Combination of metrics.
 - Problem NP-Complete → Heuristic algorithms or approximations have to be used
 - Independent metrics could have polynomial solution (i.e. BW + Delay)
- Bellman-Ford and Dijkstra implement a constrained version of their algorithms
 - Constrained Bellman-Ford (CBF) → Not good for big networks
 - QOSPF → RFC2676

Constrained Routing



- With BW bottleneck and minimum delay as QoS Requesting parameters, the path shown in the figure is chosen
 - It presents the least bottleneck restrictions → 512k
 - It presents the least delay → 3.5s



NP-Complete Table

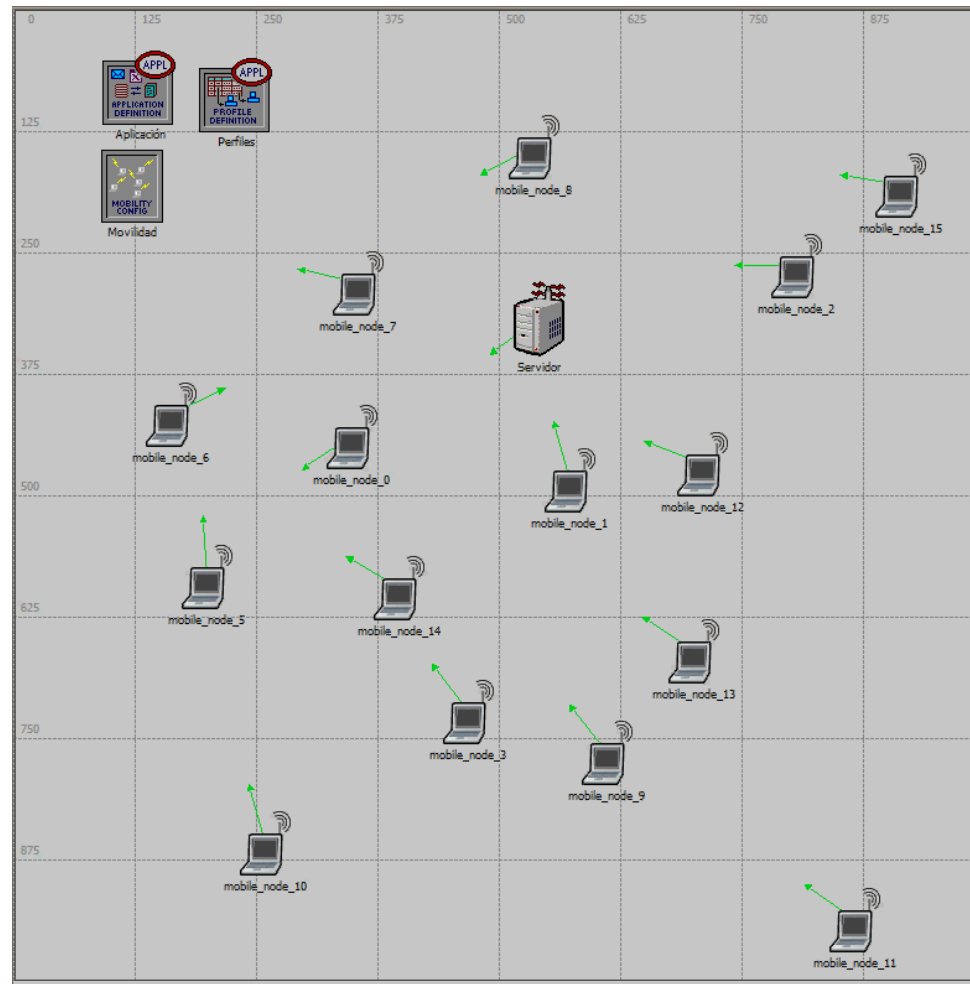
Routing Problem	Complexity
Link-Constraint path-optimization	Polynomial
Link-constraint link-optimization	Polynomial
Multi-link-constrained routing	Polynomial
Link-constrained path-constrained routing	Polynomial
Path-constrained link-optimization routing	Polynomial
Path-constrained path-optimization	NP-Complete
Multi-path-constrained routing	NP-Complete



Ad-Hoc routing

- Ad hoc networks are formed by a collection of dynamic nodes with limited transmission range → Normally more than one will be needed for a node to transmit to another node
 - Great number of Ad-Hoc routing protocols
- MANET proactive protocols
 - Maintain a fresh list of destinations and their routes.
 - More congestion in the network due to routing traffic
 - i.e. OLSR, DSDV
- MANET Reactive protocols
 - Maintain routes only between nodes that need to communicate
 - **DSR** → on-demand Dynamic Source Routing protocol
 - **TORA** → Provide multiple loop-free routes to a destination
 - **AODV** → Hop by hop routing protocol. Modified DSR protocol with some features of DSDV protocol

Ad-hoc Routing





Conclusions

- There are two different ways to find the best route to a destination
 - The shortest-path route → Considers static metrics and in recent years QoS Requests such as BW, delay, jitter, reliability; all of them in a dynamic way
 - The optimal route → The path or paths that minimize the global delay of the network
- Also SP routing is being studied in two different ways
 - Disjoint paths routing → Very complex for real-time networks
 - Multipath routing → The best option in nowadays networks
- QoS is an important fact in today networks
 - Most of the QoS routing proposals are NP-Complete and need a heuristic version or some modifications for an approximated solution