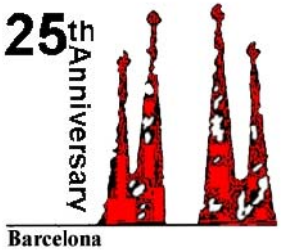
Evolution of unicast routing protocols in data networks

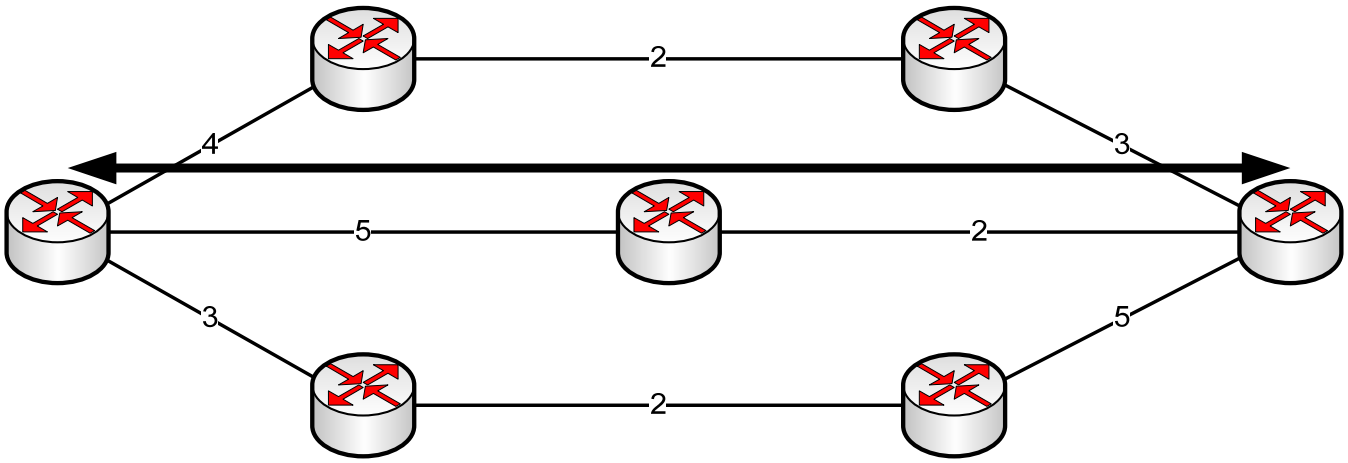
Carles Seguí
Agustín Zaballos
Xavier Cadenas
Josep M. Selga



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 Dijktra's algorithm
- **Shortest Path Routing evolution can be splitted in two branches**
  - Disjoint Shortest Path Routing
  - Multipath Routing
- **Simultanously 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

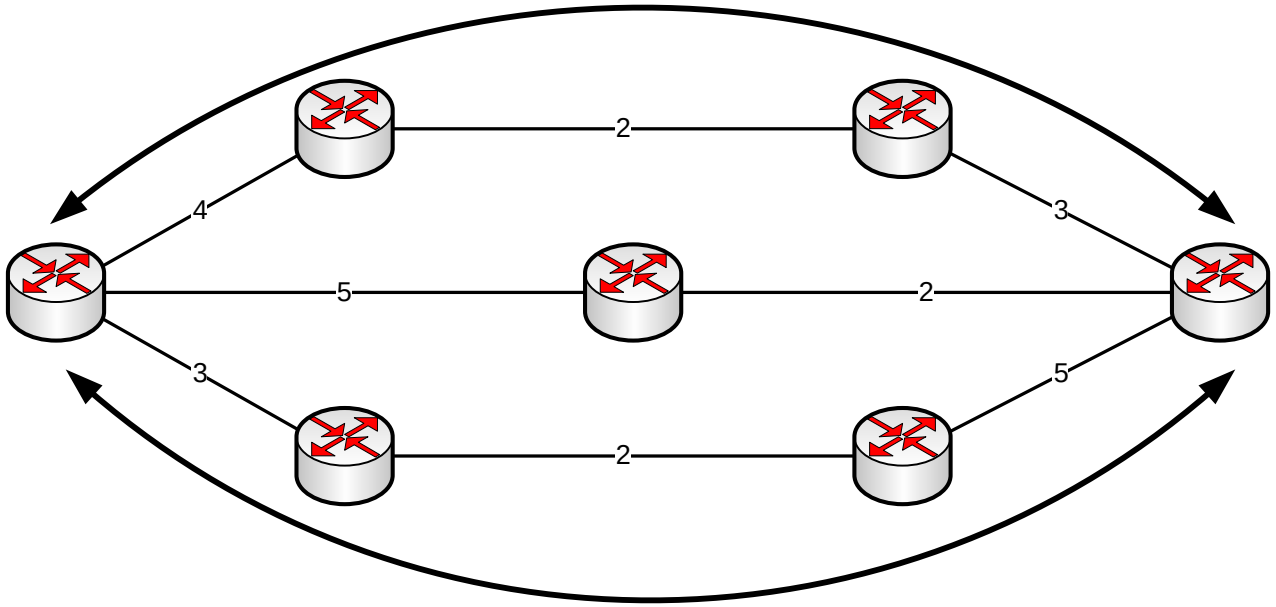


- The Shortest Path is found with static metrics
  - Bellman-Ford is based on the number of hops between source and destination (RIP)
  - Dijkstra is based on the cost of a link (OSPF, IS-IS)
  - EIGRP is based on DUAL algorithm and rely on bandwidth and delay by defaults of the links.
- If there's a 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 tecnique
  - Sidhu
    - Message distribution algorithm to mark the disjoint paths
  - Orda
    - Try to find QoS disjoint paths → NP-Complete

SP routing: Disjoint path Routing

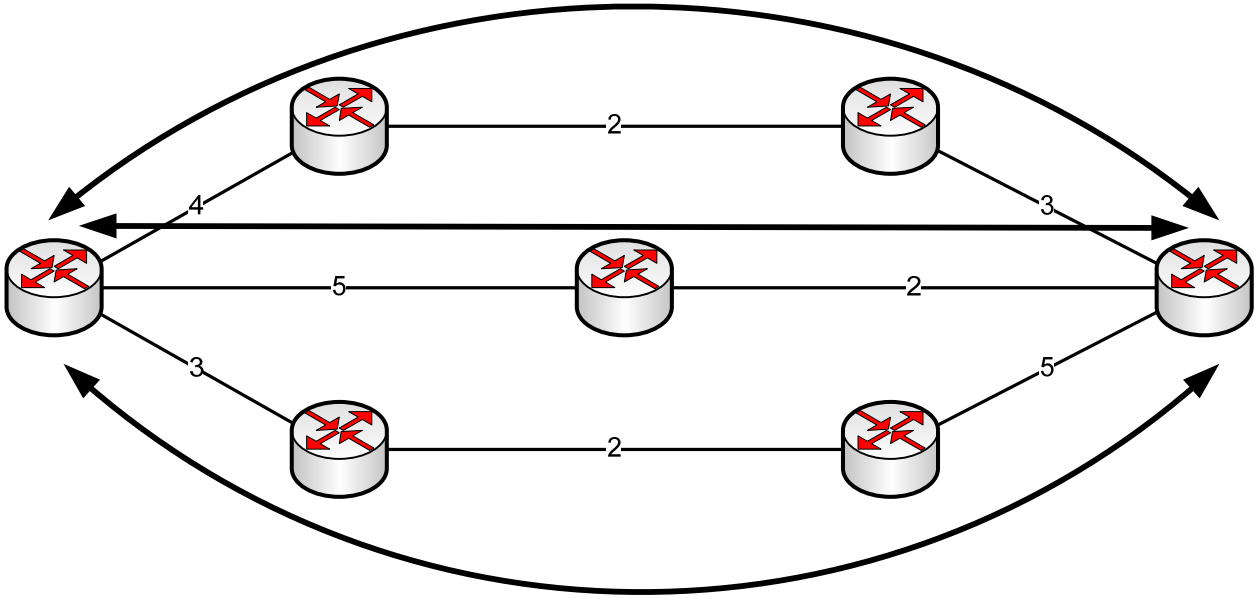


- The disjoint path routing looks for two independent paths
  - With the aumenting path, the SP could not be one of these paths
  - Sometimes it is not possible to find disjoint paths in a network

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

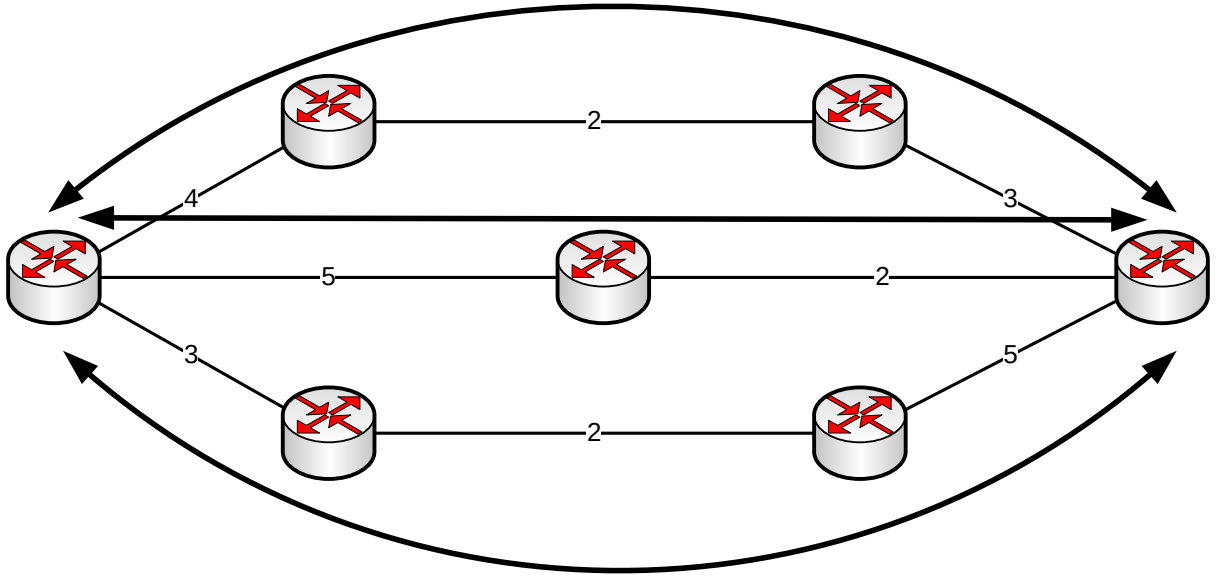


- The load-balancing could be made in different ways
  - Round Robin Load Balancing → Each packet takes a path to the destination
  - Per Flow Load Balancing → Each TCP flow takes a source-destination path
    - Important Studies of F. Kelly.

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



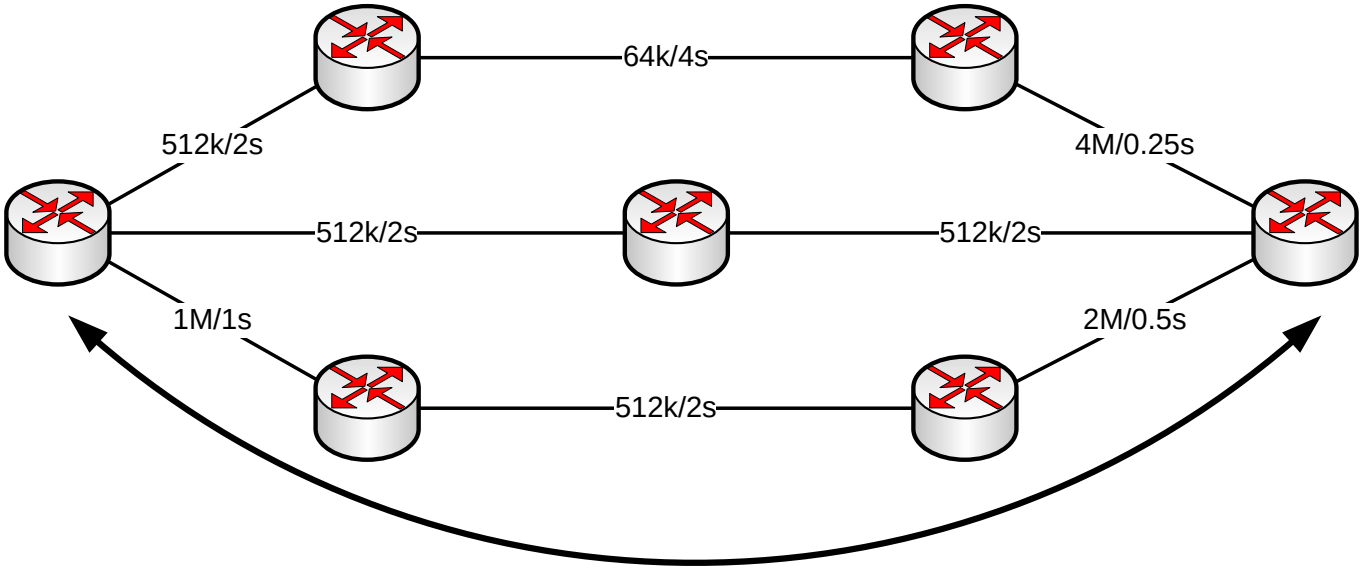
- Optimal routing find the best combination of paths that minimizes the general delay of the network

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

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 hole network.
  - Multi Constrained Routing → Combination of metrics.
    - Problem NP-Complete → Heuristic algorithms or aproximations have to be used
    - Independent metrics could have polynomial solution (i.e. BW + Delay)
- Bellman-Ford and Dijkstra implement a contrained 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 choosen
  - It presents the least bottleneck restrictions → 512k
  - It presents the least delay → 3.5s

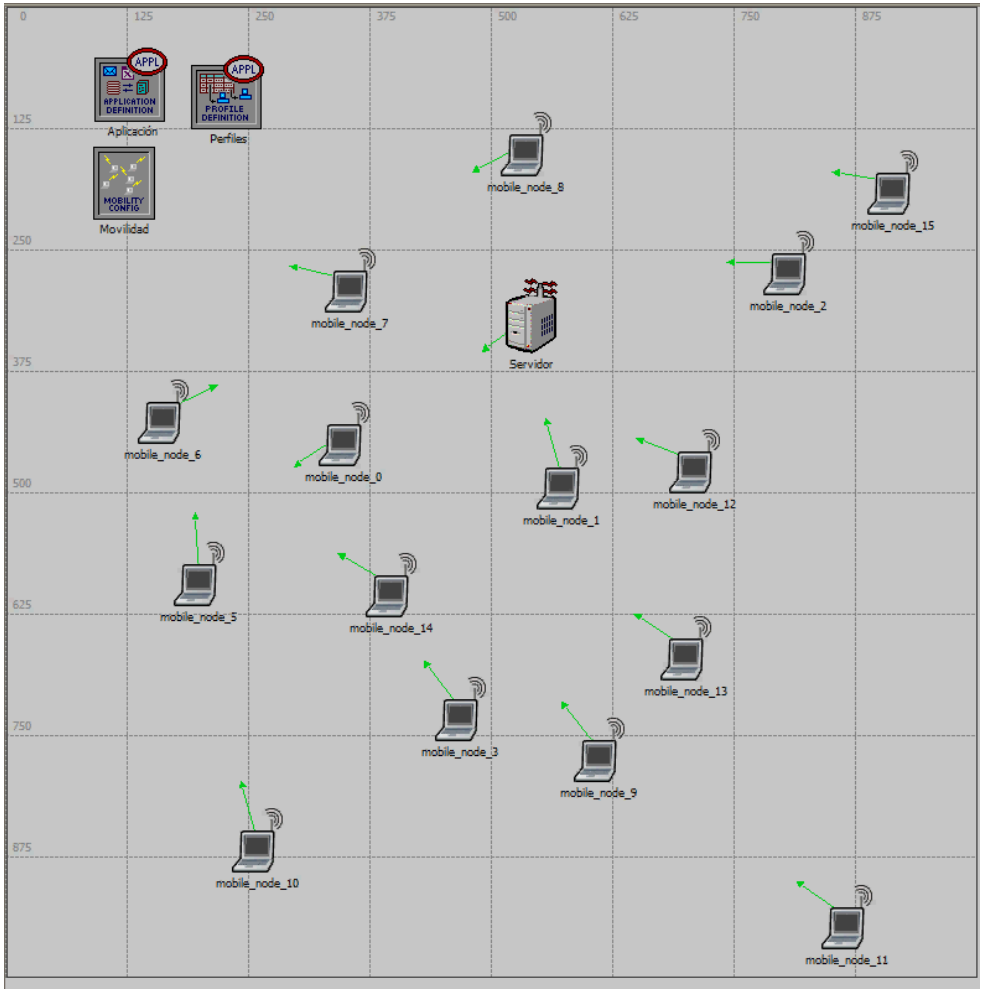
NP-Complete Table

Routing Problem	Complexity
Link-Constraint path-optimization	Polynomial
Link-constraint link-optimization	Polynomial
Multi-link-contrained 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
  - Mantain a fresh list of destinations and their routes.
  - More congestion in the network due to routing traffic
  - i.e. OLSR, DSDV
- MANET Reactive protocols
  - Mantain 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 differents 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 aproximated solution