Quality of Service Routing

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Contents

Quality of Service

- A set of service requirements to be met by the network while transporting a flow [RFC2386]

- A measurable level of service delivered to network users, which can be characterized by packet loss probability, available bandwidth, end-to-end delay, etc.

Quality of Service Provision

- Traffic Models
- Scheduling discipline
- QoS Routing
- Call Admission Control
- Etc….

QoS Routing

- A routing mechanism under which paths for flows are determined based on some knowledge of resource availability in the network as well as the QoS requirements of the flows [RFC2386]

- A dynamic routing scheme with QoS consideration [QoS Forum]

QoS Routing Mechanism

- Provisioning

  Routing: identifying a suitable topology (paths, trees)

  Resource Allocation: securing the required resources

- Restoration

  Establishing a restoration topology

    a set of restoration paths/trees

    each protecting part of the primary path/tree

QoS Metrics (1/3)

- Bandwidth, delay, jitter, cost, loss probability, etc.

- Types of metrics

  1. additive

  2. multiplicative

  3. concave

QoS Metrics (2/3)

- $m(n_1, n_2)$: a metric for link (n_1, n_2)

- For any path $P = (n_1, n_2, ..., \mathrm{n_i}, n_j)$, metric m is

  1) additive:

  $m(P) = m(n_1, n_2) + m(n_2, n_3) + \cdots + m(n_\mathrm{i}, n_\mathrm{j})$

  delay, jitter, cost, hop-count

  2) multiplicative:

  $m(P) = m(n_1, n_2) * m(n_2, n_3) * \cdots * m(n_i, n_j)$

  reliability

QoS Metrics (3/3)

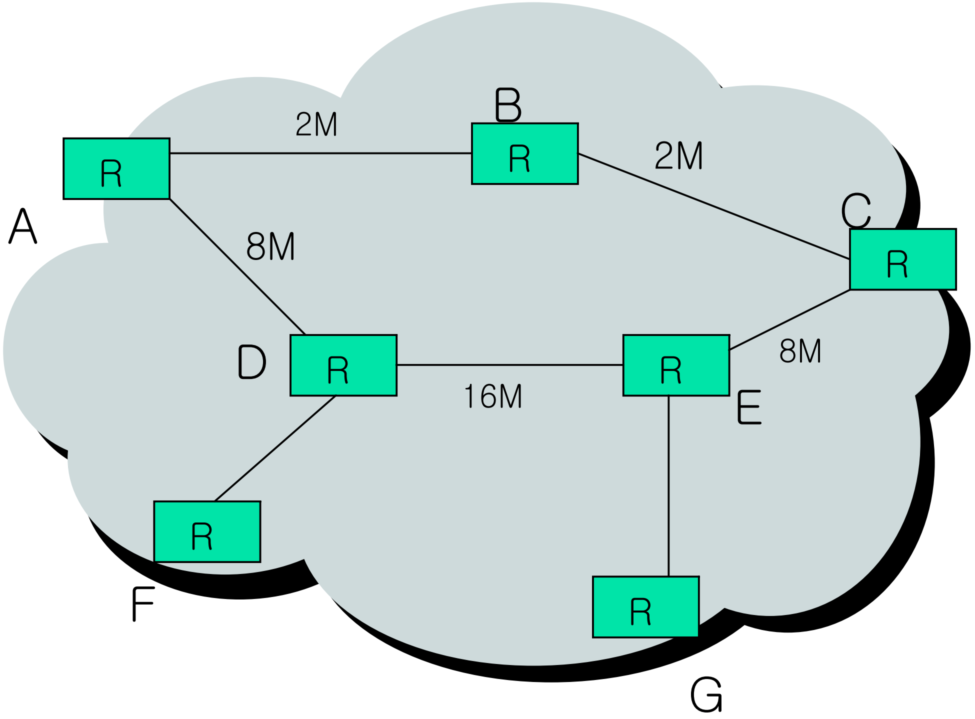
3) concave

$m(P) = min\{m(n_1, n_2), m(n_2, n_3), \cdots, m(n_i, n_j)\}$

bandwidth

- **Multiplicative problem is transformed into additive problem by assigning weight w_i to link l as $logP_i$**
- **concave problem ➔ pruning**

QoS-Based Routing Example



Traffic flow from node A to node C, which requires 4M bandwidth
- shortest path routing: A-B-C
- QoS routing: A-D-E-C

Policy-Based and QoS-Based

- **Constraint-based routing**
  - ✓ policy-based routing
  - ✓ QoS routing

- **Policy-based routing**
  - ✓ based on some administrative policies
  - ✓ not based on knowledge of the network topology and metrics
  - ✓ *Ex: a policy may prohibit a traffic flow from using a specific link for security reason*

Objectives of QoS Routing (1/2)

- **Current Internet routing are called *best effort* routing**
  - ✓ use only single objective optimisation algorithm
  - ➔ it may lead to the congestion of some links, which some other links are not fully used

- **Best-effort routing will shift the traffic from one path to better path whenever the better path is found**
  - ✓ even if the current used path meets the service requirement of the traffic
  - ➔ it will bring routing oscillation

Objectives of QoS Routing (2/2)

- **To meet the QoS requirement of end users,**
  - ✓ find the proper path from source to destination
  - ✓ should be done dynamically
  - ✓ in case of several feasible paths available, path selection can be done based on some policy constraints

- **To optimise network resource usages**

- **To gracefully degrade network performance**
  - ✓ when things like congestion happen

QoS Routing Challenges

- Coping with intractability
- Coping with scalability

  - employing a precomputation approach
- Coping with uncertainty
- Integrating with other QoS-enabling building blocks
- Implementing issues

  - Integrating with existing routing protocol

  - Distributed schemes

Issues of QoS-Based Routing (1/6)

- how to measure and collect network state information
- How to compute routes based on the information

A. metrics and path selection

1. Metric selection

    ✓ the metrics must represent the basic network properties of interest [rfc2386]

Issues of QoS-Based Routing (2/6)

2. Computing complexity

- ✓ under multiple constraints, path computation is proved to be NP-complete
- ➔ heuristic algorithms are proposed to solve the problem

3. Resource reservation

Issues of QoS-Based Routing (3/6)

B. Knowledge propagation and maintenance

- how offer the routing information is exchanged between routers
- information needed by 'best effort' routing + QoS information
- the metrics used by QoS routing could be changing very quickly
  - tradeoff between routing information accuracy and efficiency
- how to maintain the information collected
  - every flow (?)
  - flow aggregation (?)

Issues of QoS-Based Routing (4/6)

C. Scalability

- ✓ hierarchical aggregations
  - ✓ inaccuracy in regard of routing information
- ✓ region-based approach
  - ✓ no loosing the routing information

Issues of QoS-Based Routing (5/6)

D. Imprecise state information

- ✓ network dynamics
- ✓ aggregation of routing information
- ✓ hidden information
- ✓ approximate calculation
  - ✓ safety-based routing algorithm
  - ✓ use range (upper and lower bound) rather than exact values

Issues of QoS-Based Routing (6/6)

E. Administrative control

- ✓ flow priorities and preemption
- ✓ resource control
  - ✓ fairness

Requirements for QoS Routing Algorithms

- Efficient and scalable to large network
- Complexity not far greater than currently used routing algorithm
- Suitable to current (Internet) architecture

Types of QoS Routing Algorithms

- **Source-based routing algorithm**
  - ✓ every router has global state information
- **Hop by hop routing algorithm (Distributed)**
- **Hierarchical routing algorithm**
  - ✓ suitable for large network

Strengths and Weaknesses of Routing Strategies (1/3)

1. Source routing

- ✓ Advantages
  - ✓ simple and easy to implement, evaluate, debug, and upgrade
  - ✓ no problems in dealing with distribution computing problems
- ✓ Disadvantages
  - ✓ the global state maintenance at every node has to be updated frequently
    → ex. excessive communication overhead
  - ✓ approximate global state (imprecision)
  - ✓ the computation overhead at the source is excessively high

➔ Source routing has a scalability problem

Strengths and Weaknesses of Routing Strategies (2/3)

2. Distributed routing

- ✓ Advantages
  - ✓ the routing response can be made shorter
  - ✓ the algorithm is more scalable
  - ✓ hop-by-hop routing
- ✓ Disadvantages
  - ✓ global state information → similar problems, cf. source routing
  - ✓ it is difficult to design efficient distributed heuristics for NP-complete routing problems

Strengths and Weaknesses of Routing Strategies (3/3)

3. **Hierarchical routing**
   - ✓ Advantages
     - ✓ good in the scalability problems
     - ✓ small aggregated state information (only partial information)
   - ✓ Disadvantages
     - ✓ additional imprecision

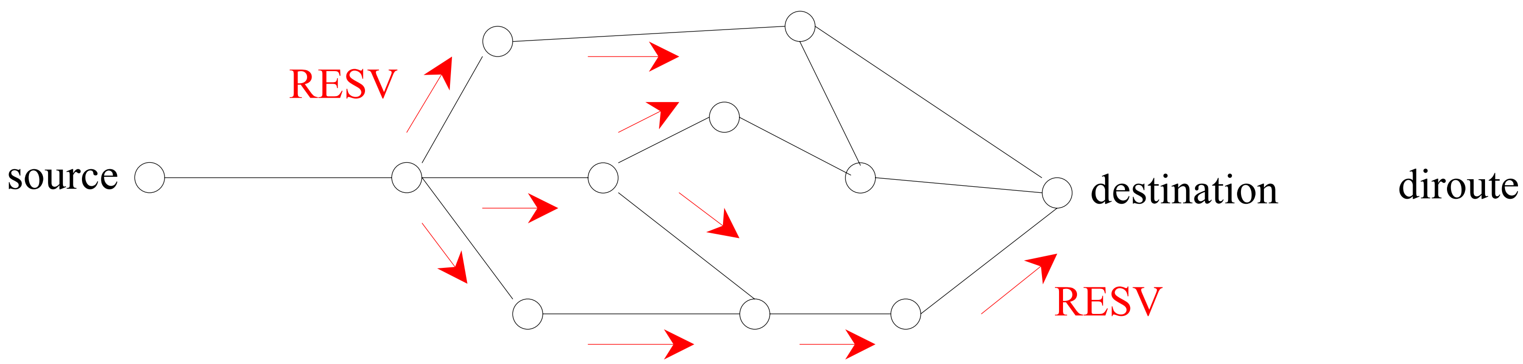
Cost and Delay

- **When both the metrics are additive, given a weight $w(u, v)$ between nodes u and v, it can be converted a new weight function**
  - ✓ $w'(u,v) = \lceil (w(u,v) * x) / c \rceil$
    (c : real number or unbound integer, x : bounded integer)
  - ✓ constraint $w \leq c \rightarrow w \leq x$
  - ✓ if L is the length of a path p, and $w(p) \leq 1$

Cost-Delay Constrained QoS Routing

- **Original cost and new-delay (u, v) = $\lceil (d(u, v) * x) / \Delta d \rceil$**
- **Original delay and new-cost (u, v) = $\lceil (c(u, v) * x) / \Delta c \rceil$**
  - ✓ x : coefficient * distance (src, dst)
  - ✓ coefficient : given positive number
  - ✓ $d(u, v)$: delay of path
  - ✓ $c(u, v)$: cost of path
  - ✓ Δd : delay constraint
  - ✓ Δc : cost constraint
- **Extended Dijkstra's algorithm and extended Bellman-Ford algorithm**
  - ✓ guarantee to find a solution if any

Cidon's Algorithm

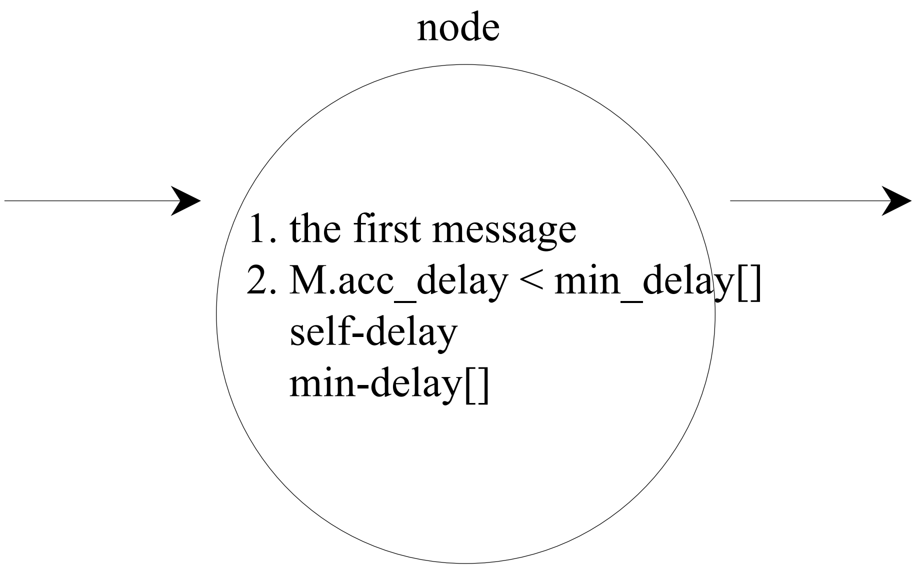


Tradeoff between routing-time and path optimality

→ increase the level of resource contention

Shin-Chou Algorithm

- **No global state information**
- **Floods routing message from source toward the destination**

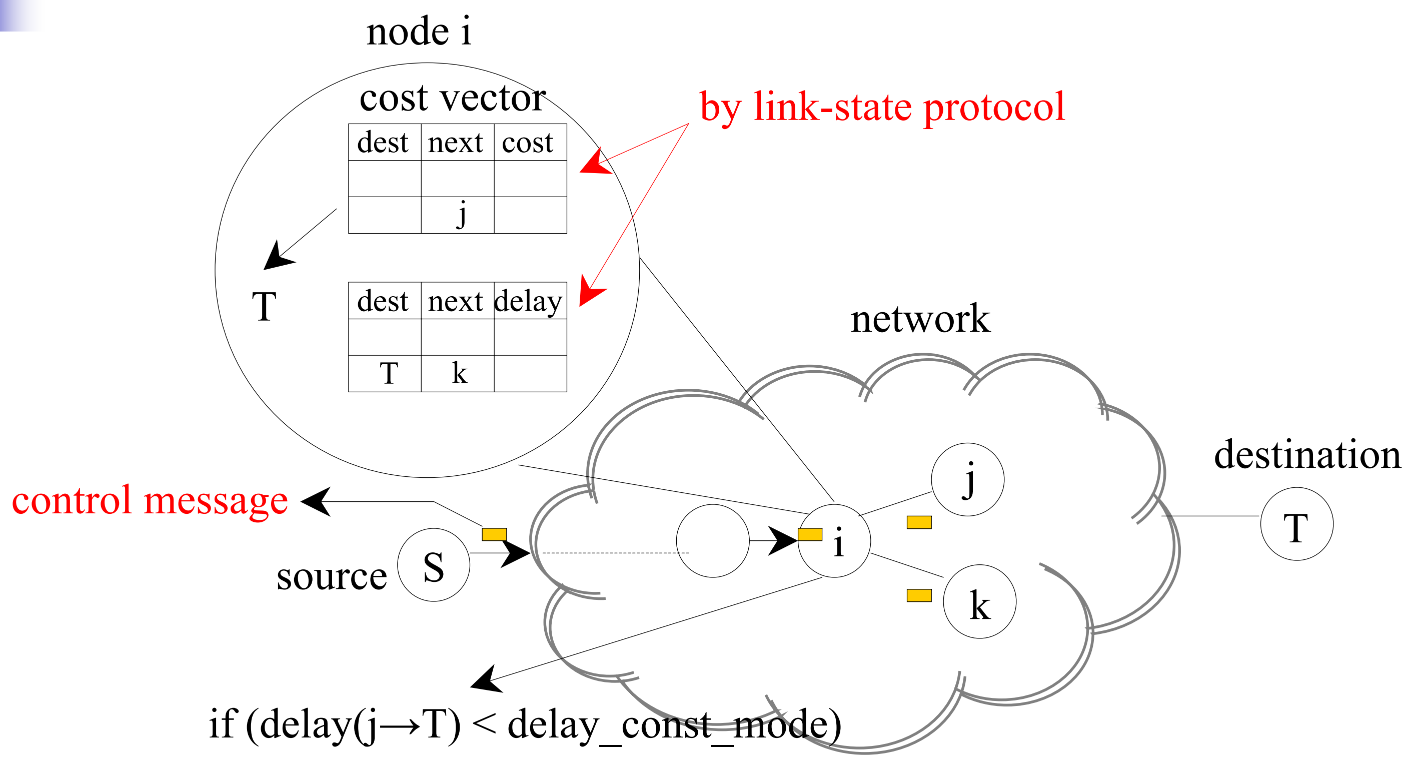


if M.acc_delay + self_delay < end-to-end delay constraint
then forward (the message M)
else
drop it

Chen-Nahrstedt (Distributed)

- **No global state information**
- **Selective probing**
- **Shin-Chou algorithm : high communication overhead**
  - ✓ forward to a subset of outgoing links
    - ✓ (based a topological distance to the destination)
  - ✓ iteration probing
    - ✓ the shortest first, the second shortest second

Salama's Algorithm



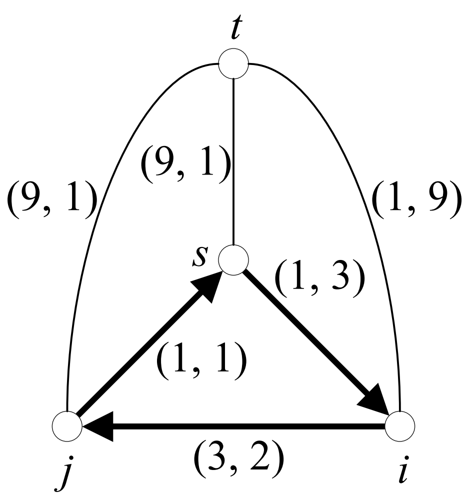
if (delay(j→T) < delay_const_mode)
    choose (j)
else choose (k)

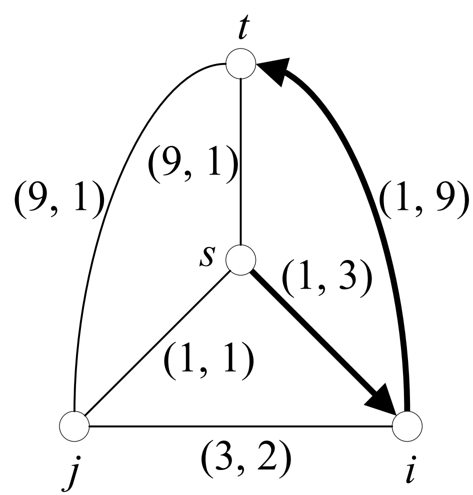
→ loops may be found (least-cost → least-delay → least-cost → …)
    detect the loop and remove it

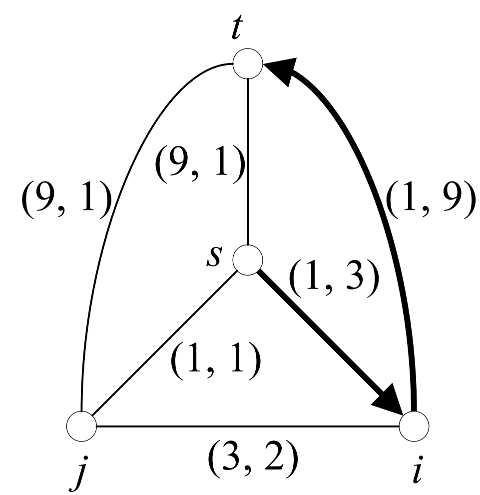
→ avoiding the loop (Sun-Landgendorfer)

Sun-Landgendorfer

- **Least-delay (priority)**
- **Least-cost path to destination**







Routing Problem (1/3)

Unicast QoS Routing

source
destination
QoS constraints (C)
optimization goal

Routing Algorithm

best feasible paths
(from s to t)

Multicast QoS Routing

source (S)
a set of destinations (R)
a set of QoS constraints (C)
optimization goal

Routing Algorithm

best feasible tree
(covering S and all nodes R)

Routing Problem (2/3)

- **link-optimization routing**
  - ✓ widest path
- **link-constrained routing**
  - ✓ bottleneck > required value
    → extended Dijkstra’s or Bellman-Ford algorithm
- **path-optimization routing**
  - ✓ least-cost routing
- **path-constrained routing**
  - ✓ bounded by a required value
    → Dijkstra’s or Bellman-Ford algorithm
- **NP-complete problem**
  - ✓ PCPO (Path-Constrained Path Optimization)
  - ✓ MPC (Multi-Path-Constrained)

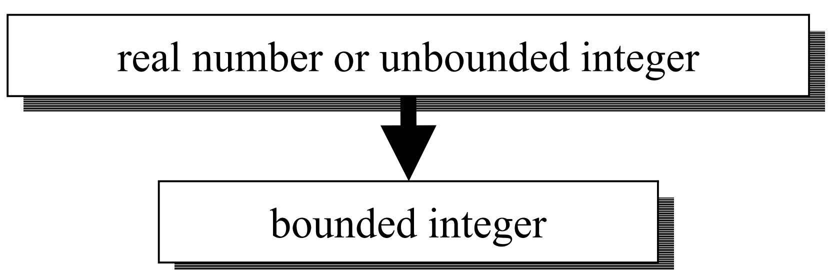
Routing Problem (3/3)

Assumption

- ✓ QoS metrics are independent
- ✓ QoS metrics are allowed to be real numbers or unbounded integer numbers

All metrics (except one) take bounded integer values, the problems are solvable in polynomial time by running and extended Dijkstra's (or Bellman-Ford) algorithm.

If all QoS metrics are dependent, it can be solvable in polynomial time.



Multiple Metrics (1/2)

- **MCOP (Multi-Constrained Optimal Path)**
  - ✓ to find a minimal cost path satisfying the constraints
  - ✓ NP-complete

➔ **Solutions :**

(1) single metric representative of the individual metrics

- ✓ $W = \alpha_1 w_1 + \alpha_2 w_2 + \ldots + \alpha_i w_i + \ldots + \alpha_n w_n$
- ✓ problem
  - if the path is optimal in the single metric, it is not necessary that it is optimal in terms of the individual metrics
  - information loss in the aggregation process
- ✓ limited path heuristics
- ✓ limited granularity heuristics
- ✓ non-linear cost function (H-MCOP) → K shortest path routing approach

$$g_\lambda(p) = \frac{w_1(p)}{c_1} * \lambda + \frac{w_2(p)}{c_2} * \lambda + \ldots + \frac{w_k(p)}{c_k} * \lambda \qquad \lambda \geq 1$$

$\lambda \uparrow$: possibility of finding a feasible path $\uparrow$

Multiple Metrics (2/2)

(2) fallback routing approach

- ✓ consider one constraint by one constraint

(3) dependent QoS metrics

- ✓ multiple dependent metrics
  → one metrics
  → (single metric : solved in polynomial time)
- ✓ Ma-Steenkiste's algorithm (WFQ : queuing delay, delay-variation, loss → a function of bandwidth)

TAMCRA

- **Tunable Accuracy Multiple Constraints Routing Algorithm**
  - ✓ based on
    - ✓ non-linear measure of the path length
    - ✓ k-shortest path approach
    - ✓ principle of non-dominated path

QoS Multicast Routing

Problems

- ✓ scalability to large groups
- ✓ support for dynamic membership
- ✓ support for receiver-initiated, heterogeneous reservations

Conclusion

- **QoS routing is a highly complex problem**
- **Its solution is invaluable for the technological and economical success of communication networks**
- **Efficient, scalable and provable approximation schemes can be employed**
- **Related Conf. 1st WqosR (2004.10.1)**