Centralized and distributed heuristic algorithms for application-level traffic routing

Problems in application-level traffic routing

- If a user chooses an application-level (AL) route ignoring other users' AL routes, some AL routes share the same AL link
- AL routes may include more IP links than IP-level routes
- The number of traversed transit links increases, which means that transit cost in the whole network increases

Our goal

1. Formulate the application-level traffic routing as an optimization problem
2. Propose heuristic algorithms to obtain near-optimal solutions to the problem
   - We propose both centralized and distributed algorithms to accommodate wide-range application scenario

Network model

AL routes optimization problem

- Find the set of AL routes, each of which provides optimal performance for the AL node pair
- AL route must be chosen considering usages of AL links by any other AL routes
- Because the AL link usages by AL routes affect performance of routes each other
- Since the problem is NP-complete [4], we utilize heuristic algorithm to solve the problem

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Background: Application-level traffic routing

- Routing mechanism worked on application layer
- It uses user-perceived routing metrics such as end-to-end latency and available bandwidth
- It can improve user-perceived performance using detour route traversing another end-host

- The performance gain is mainly based on the difference between the policy of IP routing and that of application-level traffic routing
- IP routing is based on router-level hop count, AS-level hop count and commercial contracts with neighboring ISPs, which is not always suit user-perceived performance

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- End-to-end latency and decreasing available bandwidth
- Transit link increases, which means that transit cost in the whole network increases
Centralized heuristic algorithm

- The proposed heuristic algorithms search a set of AL routes from the available AL routes, each of which provides near-optimal performance for the AL node pair.
- Centralized algorithm utilizing simulated annealing
  - The set of AL routes that are utilized by AL node pairs is regarded as state $S$.  
  - Neighbor state is generated by changing some AL routes of the present state to randomly generated AL routes.  
  - A metric of expected network performance as the cost of state $S$.  
  - It is calculated by the cost of AL links and routes.
  - How to derive the cost of AL links and routes
    - Cost of AL links and routes is defined as the expected network performance when the set of AL routes is used, which is calculated as follows.
    - End-to-end latency
    - Latency of each AL link is derived by MEM's queuing model using available bandwidth and link utilization.
    - We regard the sum of latency of all AL links on the AL route as the end-to-end latency of the AL route.
    - Available bandwidth
      - Available bandwidth of each AL route is attached by max-min algorithm.
    - We regard the minimum value of all AL links on the AL route as the available bandwidth of the AL route.
    - Transit cost
      - We classify IP links included by AL links as intra-AS link, peering link, and transit link.
    - The transit cost of AL route is derived according to the traffic demand of the AL node pairs and kinds of inter-AS links on the AL route.

Distributed heuristic algorithm

- Distributed algorithm utilizing distributed simulated annealing [1]
  - Run in each AL node independently.
  - Each AL node measures the network performance of AL links whose source node is the AL node.
  - Each AL node generates the neighbor state for simulated annealing only with the AL routes whose source node is the AL node.
  - The process of distributed simulated annealing is differed from that of centralized, because the centralized algorithm targets all AL routes.
  - Each AL node exchanges the information about the AL routes and network performances with other AL nodes.  
  - Each node calculates the cost of state with the information exchanged with other nodes.
  - The notification of AL routes to other AL nodes makes communication overhead.

Performance evaluation

- Evaluate the proposed algorithms by assuming that the PlanetLab nodes construct an AL network and conduct an AL routing.
- The process of obtaining the network performance values is as below.
  - End-to-end latencies, IP-level routes
    - We conducted traceroute commands between all PlanetLab nodes.
  - Available bandwidth, physical capacities
    - We obtained the measurement results available at Scalable Sensing Service (S5) [3].
  - AS-level routes
    - We converted the IP-level routes to AS-level routes by using the relationship information between IP address prefix and AS numbers that is available at Route Views Project [1].
  - Relationship information between ASes
    - We utilized the relationship information provided by CAIDA [5].

Settings for the evaluation

- Measured network performances of AL links
  - For centralized algorithm, all AL nodes obtained the network performances in advance.
  - For distributed algorithm, each AL node obtained the network performance assigned to itself in advance and can exchange the network performance of other AL nodes.
- Value of traffic of each AL node pair
  - 1000 bits per AL node pair
- Initial state of simulated annealing
  - One-hop AL routes that are equal to the IP-level routes are utilized.
- Neighbor state generate function
  - Neighbor state is generated from the present state by changing 3% of the target AL links to randomly generated AL routes.
- Exchange frequency of AL routes information
  - Exchange the AL routes information every 100 iteration of distributed simulated annealing.
Ref. Formulation of application-level routing (1/2)

Definition of IP-level routing matrix
- Describe IP link usages by IP routes between IP routers as a matrix.

AL (application-level) network
- AL nodes located at end-hosts connected to IP routers.
- AL nodes are connected each other by AL links.

Route matrix of AL nodes
- Each AL link is equal to the IP route between the AL nodes.
- AL route between AL nodes consists of one or more AL links.

The equation means that the AL route that consists of available AL links

Ref. Formulation of application-level routing (2/2)

Definition of AL routing matrix
- The AL routing determines an AL route from available routes for each AL node pair that has traffic demand.
- Describe AL link usage as a matrix.

Derive the end-to-end network performance provided by the AL routes
- Using the AL routing matrix and the matrix of traffic demand between AL nodes.

Elements of follow equations represent the end-to-end latency, available bandwidth, and cost of AL links, respectively.

Conclusion and future work

Conclusion
- Proposed the centralized and distributed heuristic algorithms for application-level traffic routing.
- Evaluated the proposed algorithms assuming that PlanetLab nodes performed an AL routing.
- We confirmed that the proposed algorithms could achieve near-optimal solutions as well as considerable improvement in end-to-end network performance.

Future work
- Evaluate the proposed algorithms with more than one metrics such as minimizing end-to-end latency under a constraint on transit cost.
- Extend the proposed algorithms appropriately to the protocol developed by Application-layer Traffic Optimization (ALTO).
Ref. Optimization problem of application-level routes

Define the optimization problem for user-perceived performance and transit cost:

\[ \text{Minimize} \] \[ \sum_{c \in K} \frac{T_c}{|K|} \]

\[ \text{Subject to:} \]
- If an AL route selection of each AL node pair does not affect the network performance of other AL routes, the problem is equal to that the problem to minimize/maximize the performance of each AL route independently
- In practice, an AL route selection of each node affects the network performance of other AL routes each other
- We adopt heuristic algorithm because the problem is NP-complete[1] and cannot be solve with exhaustive search