On Selfish Routing In Internet-like Environments

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Selfish Routing

- **IP routing is often sub-optimal in terms of user performance**
  - Many causes
    - policy routing, failures, instability
- **Emerging trend: Autonomous routing**
  - End users choose their own routes
    - Source routing (e.g. Nimrod)
    - Overlay routing (e.g. Detour, RON)
  - is selfish by nature
    - End hosts or routing overlays greedily select routes to optimize their own performance without considering system-wide criteria
  - Roughgarden proved: for general latency functions (e.g., \( M/M/1 \)) and topologies, the “worst-case ratio between the total latency of selfish routing and that of the global optima” can be unbounded.
  - But other theoretical works (e.g., Friedman) have also shown the degradation is “less severe in some perspectives.”
Questions

1. **Selfish source routing**
   - How does selfish source routing perform?
     - Are Internet-like environments among the worst cases?

2. **Selfish overlay routing**
   - How does selfish overlay routing perform?
     - Note that routing on an overlay has much less flexibility than routing directly on the physical network.

3. **Horizontal interactions**
   - Does selfish traffic co-exist well with compliant traffic?
   - Do selfish overlays co-exist well with each other?

4. **Vertical interactions**
   - How does selfish traffic interact with the underlying network control process, i.e. traffic engineering?
Routing Schemes

- **Routing on the physical network**
  - Source routing
  - Latency optimal routing

- **Routing on an overlay (less flexible!)**
  - Overlay source routing
  - Overlay latency optimal routing
    - Cooperative within an overlay, but selfish across overlays

- **Compliant (i.e. default) routing: OSPF**
  - Hop count, i.e. unit weight
  - Optimized weights
    - Minimize network cost [FRT02]
  - Random weights
Our Approach

• We take a game-theoretic approach to partially answer these questions through simulations
  - Metrics: avg user latency, max system link utilization, and network costs.
  - Algorithms to compute metrics of selfish and optimal routing. Simulate to find metrics of compliant routing.
  - M/M/1 latency function (others yield similar results).
  - Focus on intra-domain environments
    • Compare against theoretical worst-case results
    • Can use realistic topologies and traffic demands
1. Selfish Source Routing: Average Latency

Good news: Internet-like environments are far from the worst cases for selfish source routing.
1. Selfish Source Routing (cont):
Network Cost

Bad news: Low latency comes at much higher network cost
Selfish Overlay Routing and Horizontal Interactions

• **Similar results**
  - Selfish overlay routing
    • Close to optimal average latency at higher network cost.
    • Similar results whether overlay covers all physical nodes, or random (20-100%), or only edge nodes.
  - ‘Horizontal interactions’
    • Selfish overlays and compliant traffic can co-exist.
    • Multiple selfish overlays can co-exist.
4. Vertical Interactions

- **Vertical interaction:**
  An iterative process between two players
  - Traffic engineering: minimize network cost
    - current traffic pattern $\rightarrow$ new routing matrix
  - Selfish overlays: minimize user latency
    - current routing matrix $\rightarrow$ new traffic pattern

- **Question:**
  - Will the system reach a state with both low latency and low network cost?

- **Short Answer:**
  - It depends on how much control physical routing has.
Selfish Overlays vs. OSPF Optimizer

OSPF optimizer interacts poorly with selfish overlays because it only has very coarse-grained control.
MPLS optimizer interacts with selfish overlays much more effectively.
Conclusions

• Formulate a set of important research questions on selfish routing
• Use game theory and simulations to partially answer them in the intra-domain context
• A number of interesting findings
  - In contrast to the theoretical worst cases, selfish routing achieves close to optimal latency in Internet-like environments.
  - Selfish overlays co-exist well both with each other and with traffic using default IP routing.
  - Mismatch between objectives of selfish overlays and traffic engineering has significant impact on system performance.