

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 (eg, $M/M/1$) 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 (eg, 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?

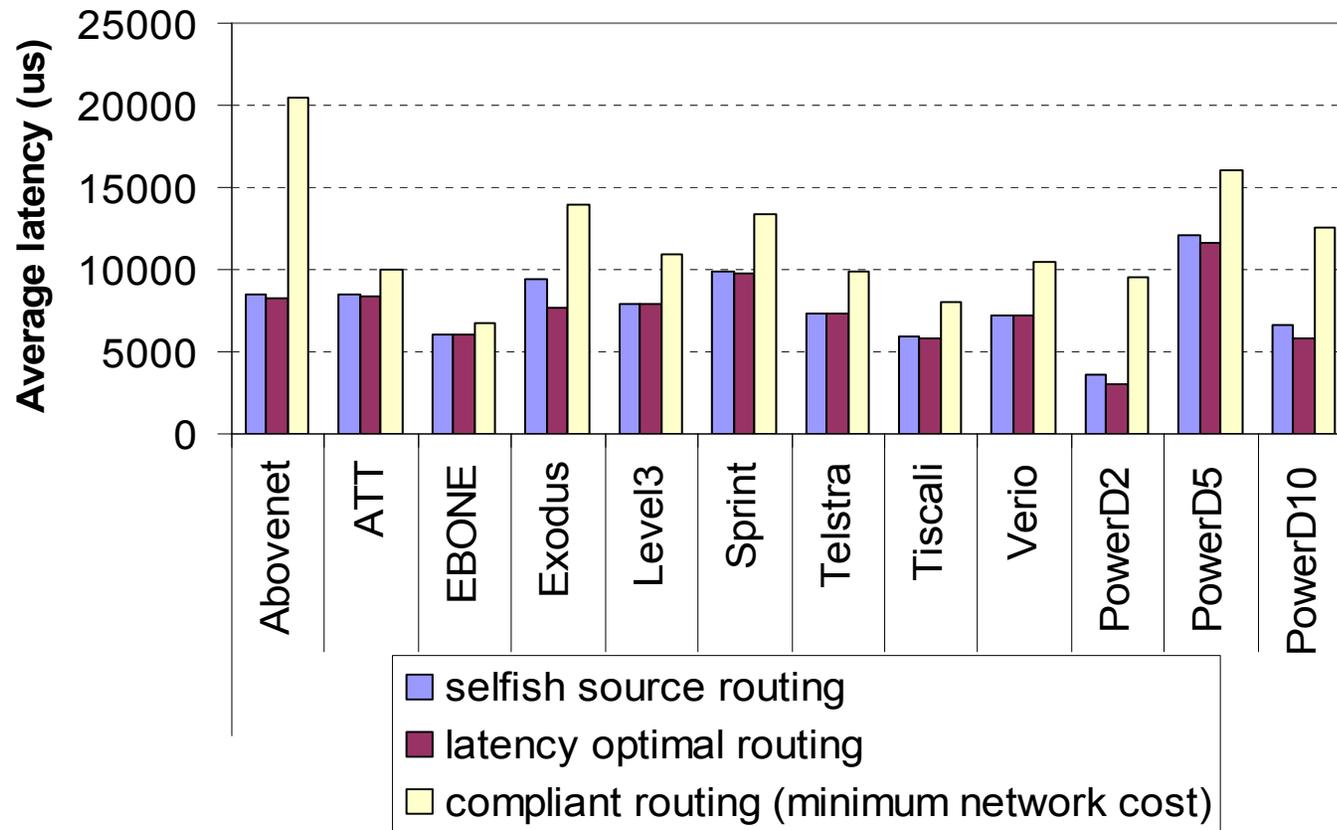
Routing Schemes

- 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

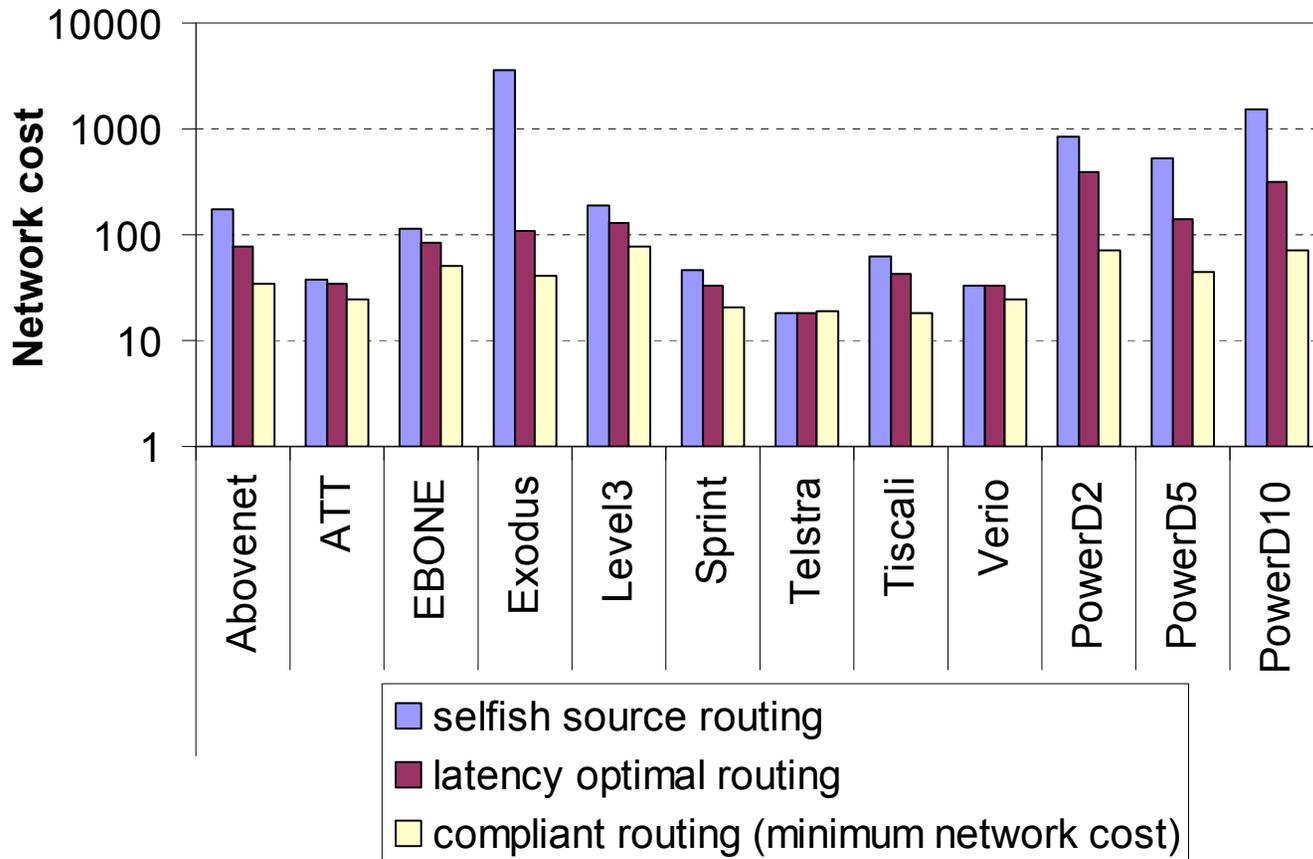
- We take a game-theoretic approach to partially answer these questions through simulations
 - Metrics: avg user latency, max system link utilization, and network costs.
 - Algorithms to compute metrics of selfish and optimal routing. Simulate to find metrics of compliant routing.
 - $M/M/1$ latency 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

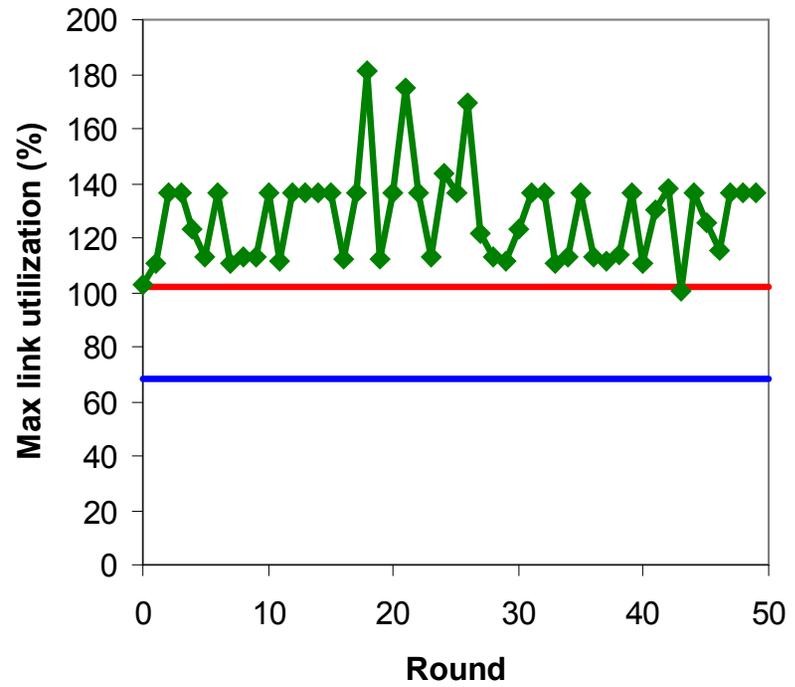
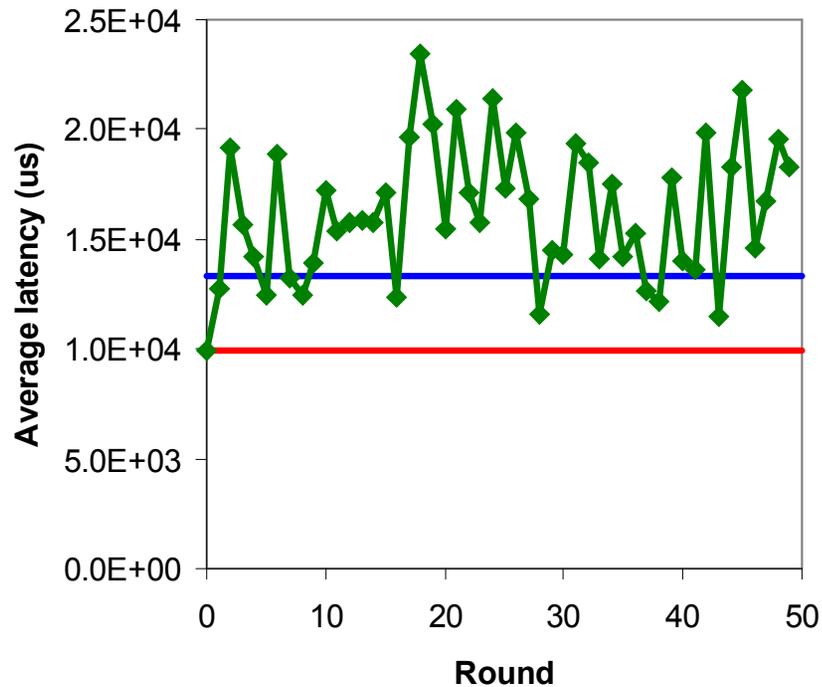
Selfish Overlay Routing and Horizontal Interactions

- 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

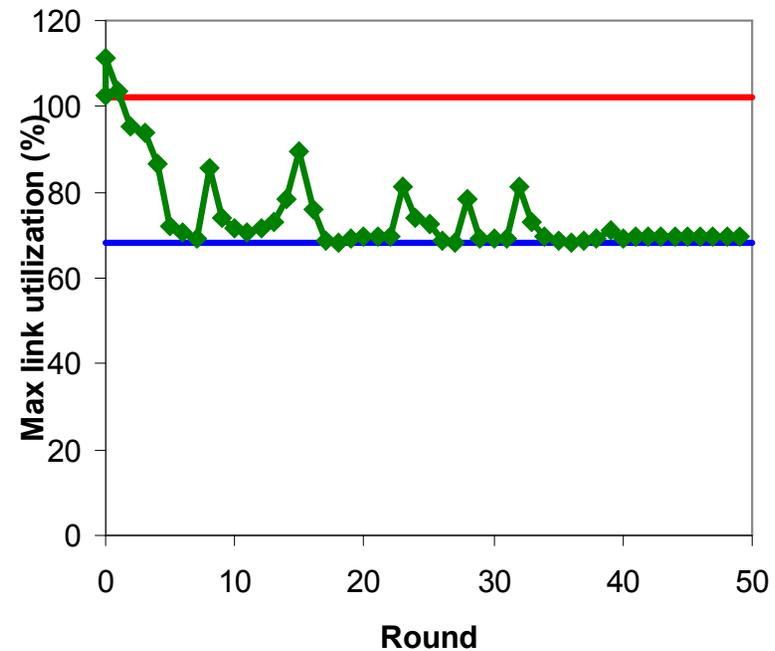
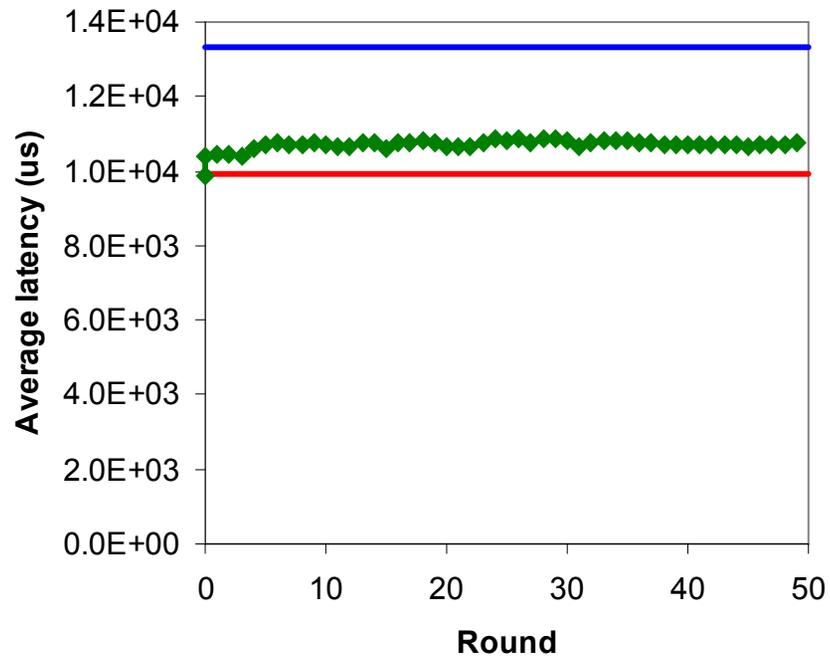
- Vertical interaction:
 - An iterative process between two players
 - Traffic engineering: minimize network cost
 - current traffic pattern → new routing matrix
 - Selfish overlays: minimize user latency
 - current routing matrix → new traffic pattern
- Question:
 - Will the system reach a state with 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.

Selfish Overlays vs. MPLS Optimizer



— selfish alone — TE alone —◆— selfish + TE (MPLS)

— selfish alone — TE alone —◆— selfish + TE (MPLS)

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.