

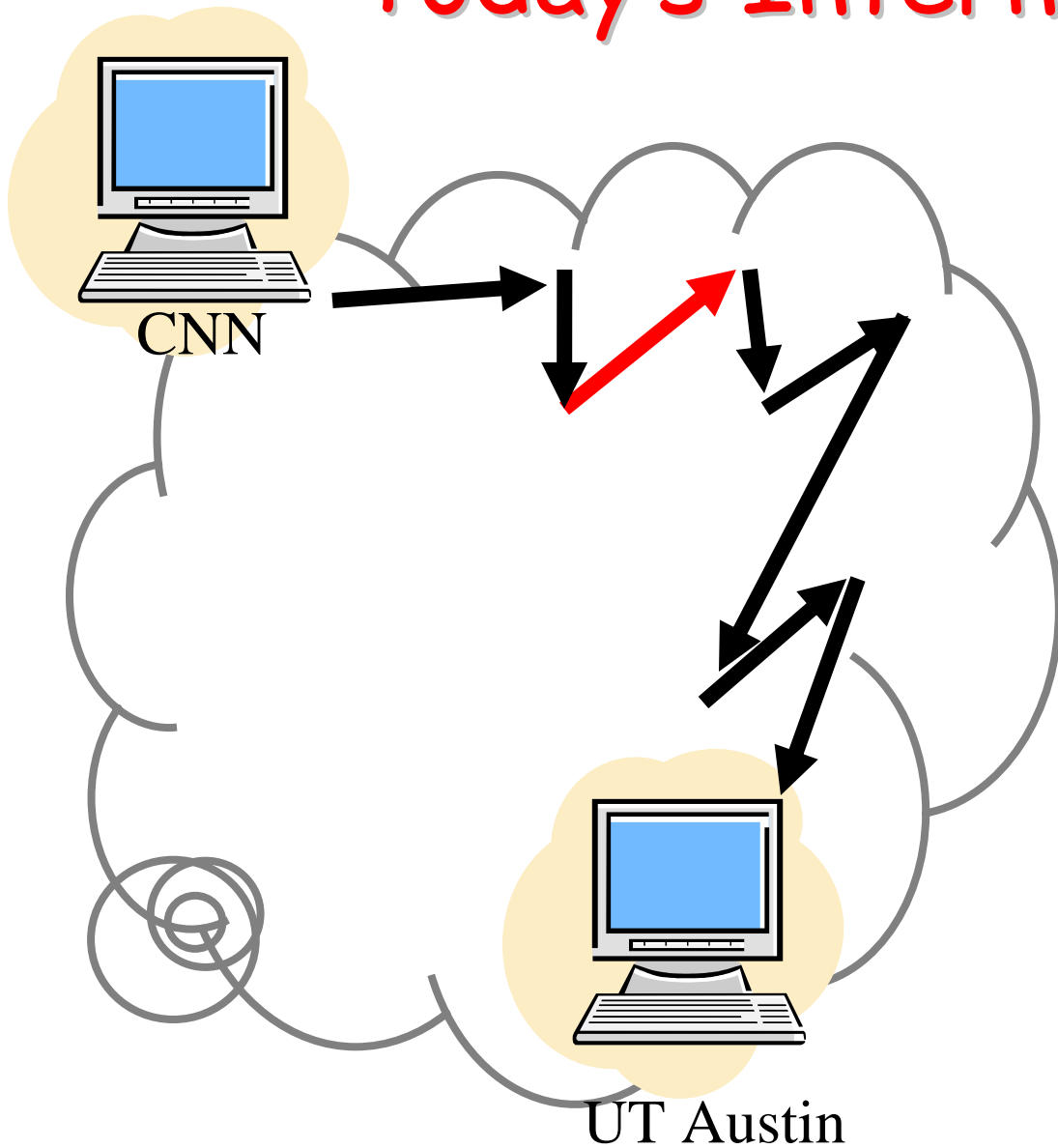
# On Selfish Routing In Internet-like Environments

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# Today's Internet Routing



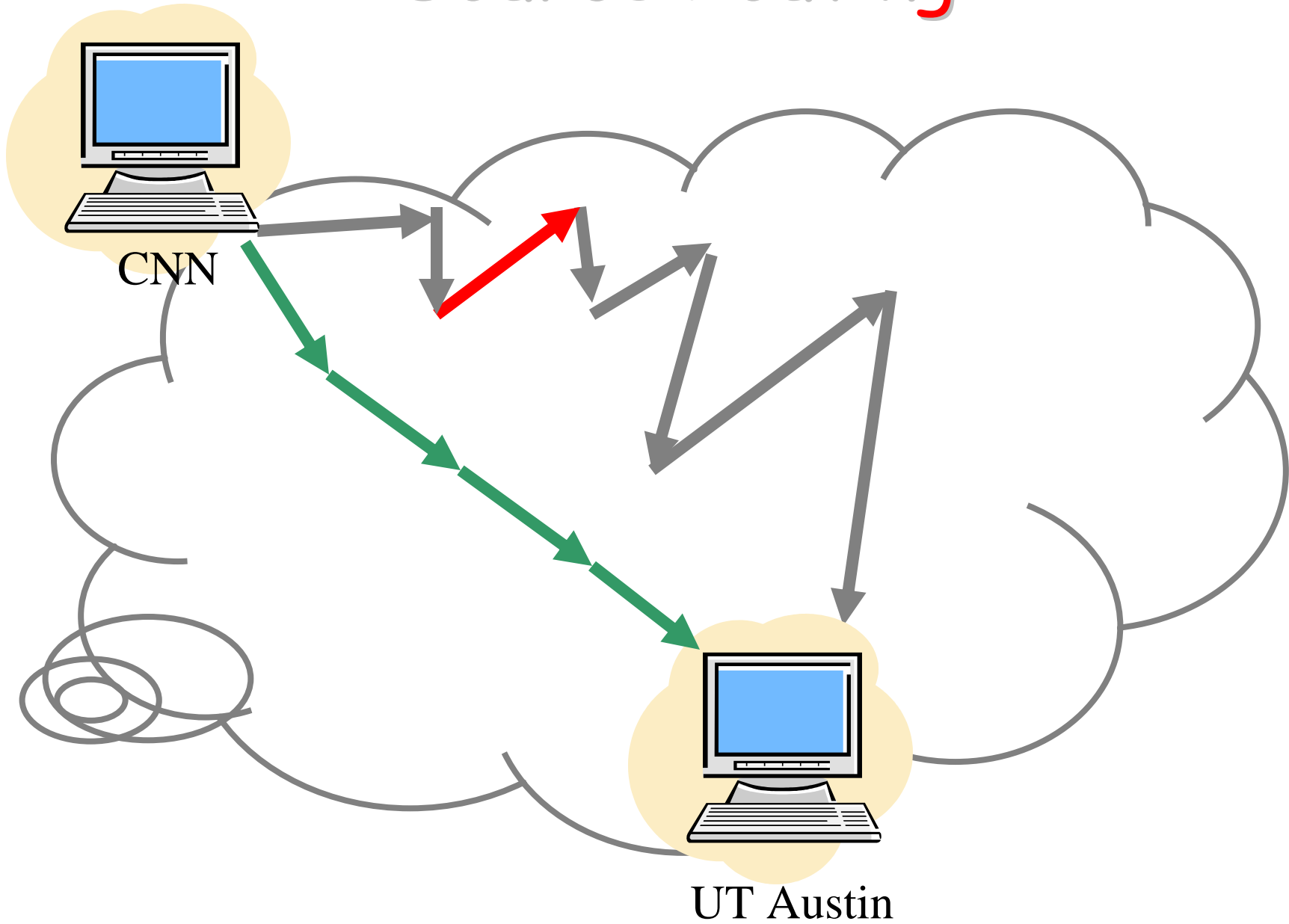
- Network in charge of routing
- Route selection affects user performance
- IP routing yields **sub-optimal** user performance



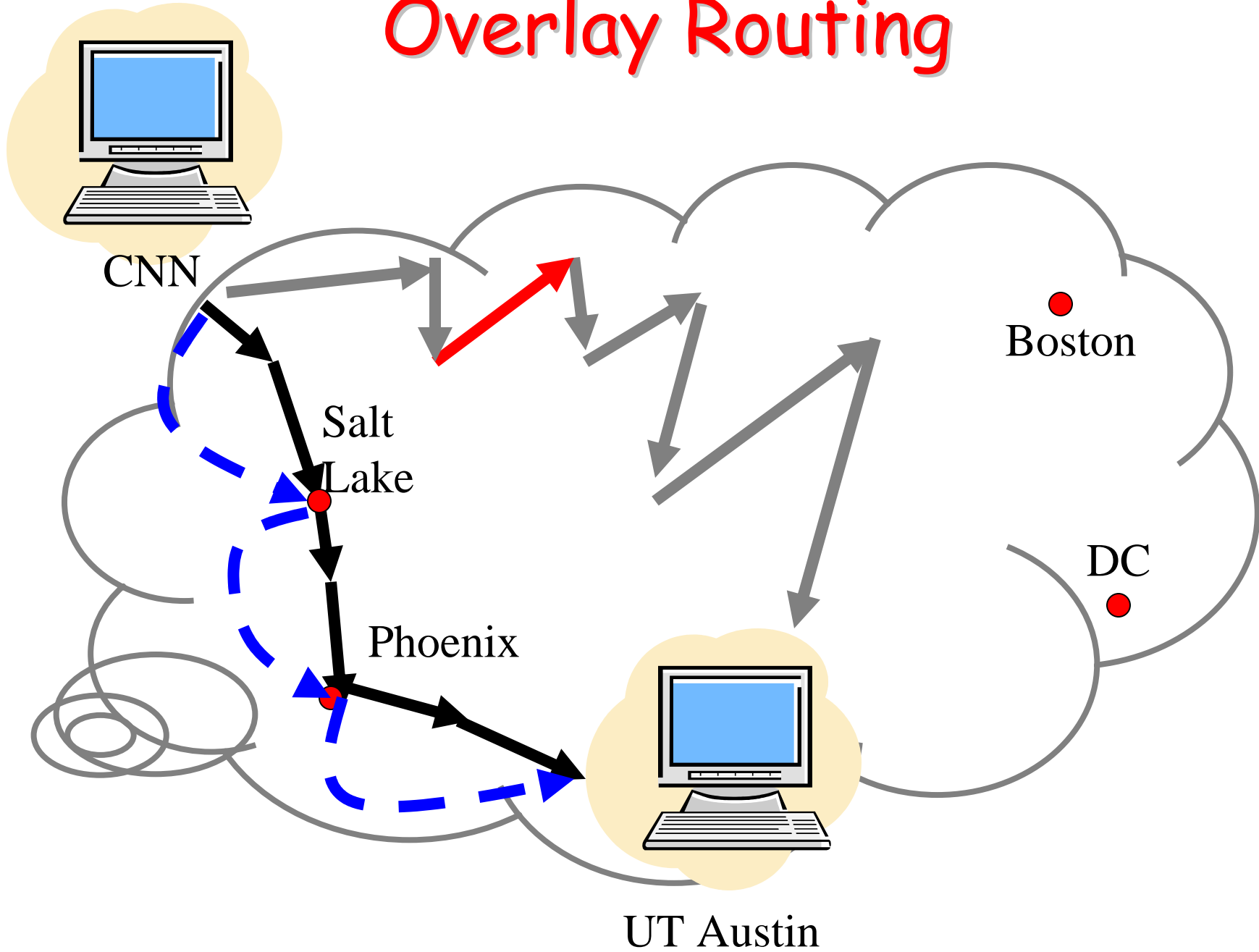
# Selfish Routing

- Selfish routing: users pick their own routes
  - Source routing (e.g., Nimrod)
  - Overlay routing (e.g., Detour, RON)

# Source Routing



# Overlay Routing

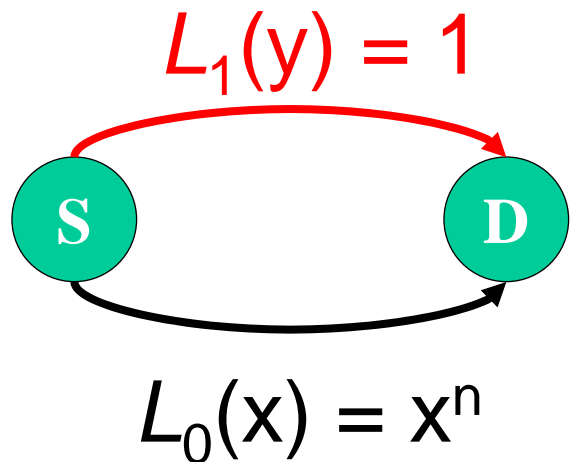


# Selfish Routing

- Selfish nature
  - End hosts or routing overlays greedily select routes
  - Optimize their own performance goals
  - Not considering system-wide criteria
- Studies based on small scale deployment show it improves performance
- How well does selfish routing perform if everyone uses it?

# Bad News

- Selfish routing can seriously degrade performance [Roughgarden & Tardos]



Total load:  $x + y = 1$

Mean latency:  $x L_0(x) + y L_1(y)$

Worst-case ratio is unbounded

- Selfish source routing

- All traffic through lower link

→ Mean latency = 1

- Latency optimal routing

- To minimize mean latency, set  $x = [1/(n+1)]^{1/n}$

→ Mean latency → 0 as  $n \rightarrow \infty$

# Questions

- **Selfish source routing**
  - How does selfish source routing perform?
  - Are Internet environments among the worst cases?
- **Selfish overlay routing**
  - How does selfish overlay routing perform?
  - Does the reduced flexibility avoid the bad cases?
- **Horizontal interactions**
  - Does selfish traffic coexist well with other traffic?
  - Do selfish overlays coexist well with each other?
- **Vertical interactions**
  - Does selfish routing interact well with network traffic engineering?

# Our Approach

- Game-theoretic approach with simulations
  - Equilibrium behavior
    - A state where no user can improve the latency of its traffic by unilaterally changing its routing
    - Apply game theory to compute traffic equilibria
    - Compare with global optimal and default IP routing
- Disclaimers
  - Some simplifications & assumptions
    - Necessary to limit the parameter space
  - Raise more questions than what we answer
    - Lots of ongoing and future work

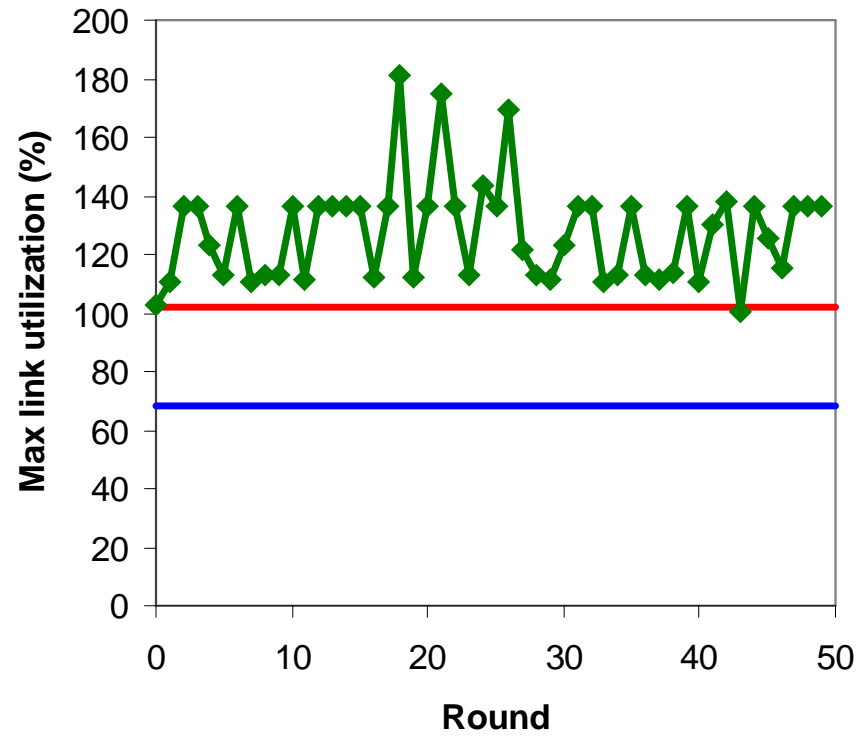
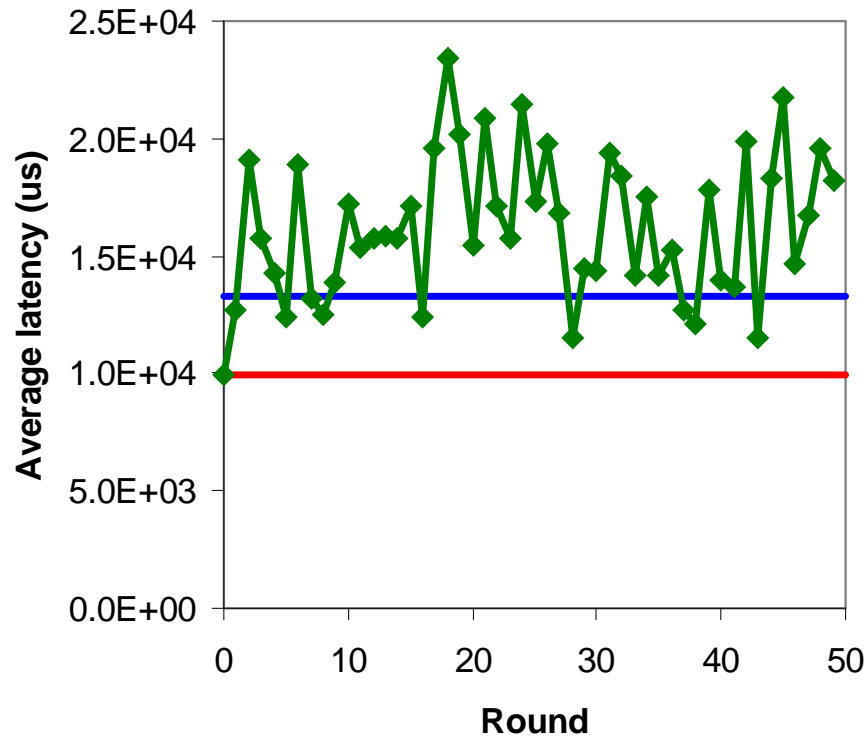
# Major Findings

- Near-optimal latency in Internet-like environments
  - In contrast with the theoretical worst cases
- Coexists well with other overlays & regular IP traffic
  - Background traffic may even benefit in some cases
- Big interactions with network traffic engineering
  - Tension between optimizing user latency vs. network load

# Interactions with Traffic Engineering

- 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:
  - Does system reach a state with both low latency and low network cost?
- Short answer:
  - Depends on how much control the network has

# Selfish Overlays vs. OSPF Optimizer

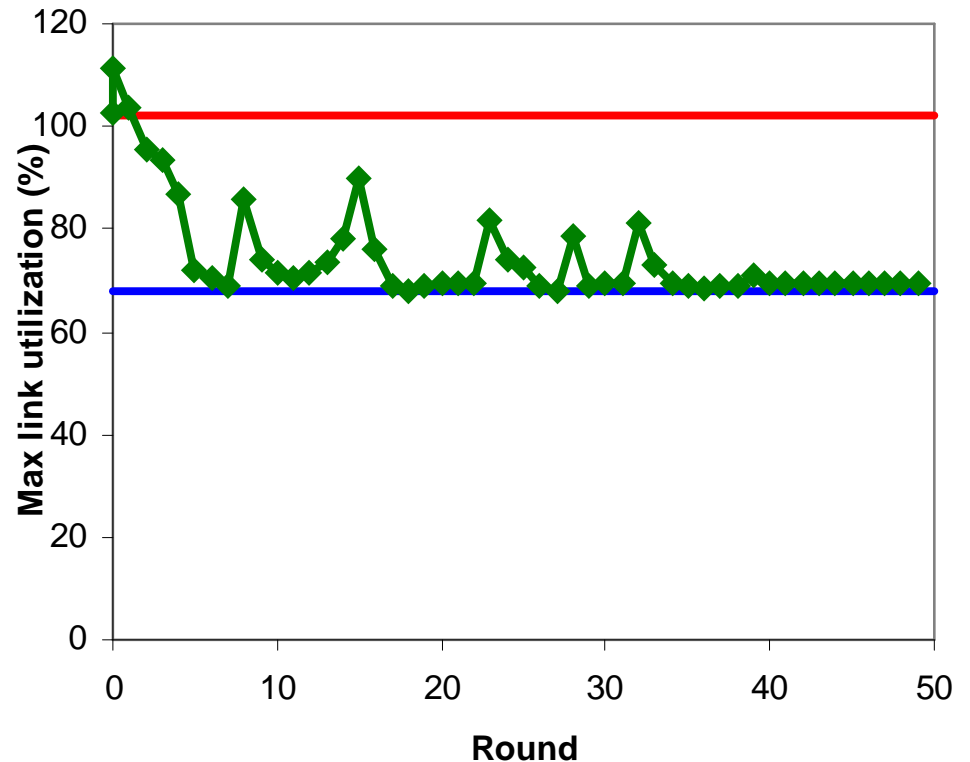
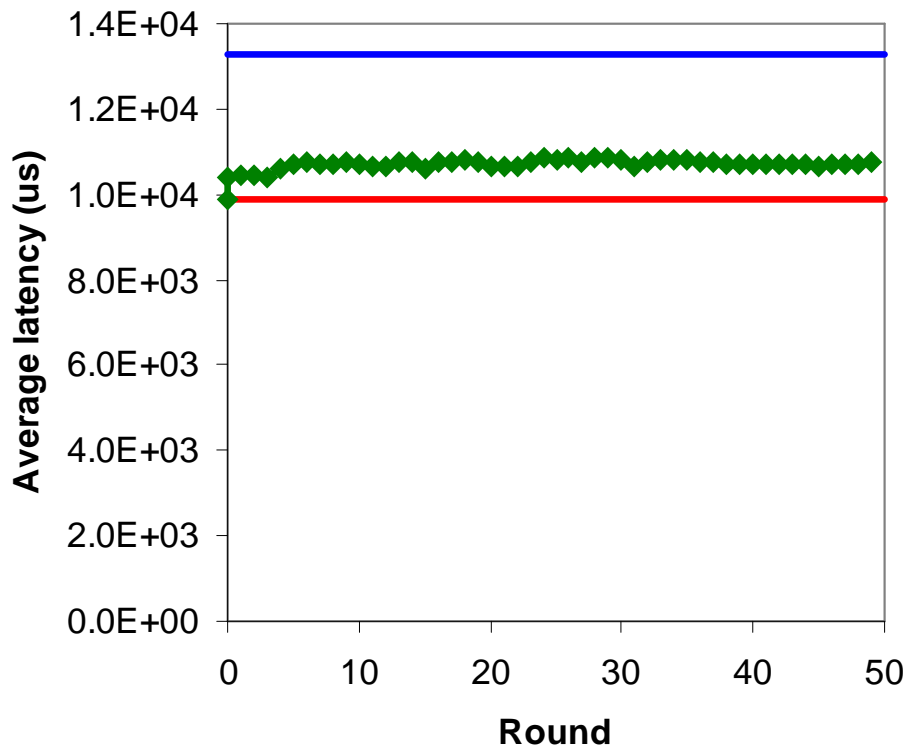


— selfish alone      — TE alone  
—◆— selfish + TE (OSPF)

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

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.