Non-preemptive Coflow Scheduling and Routing

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Outline

- **Introduction and Motivation**
- System Model and Algorithm Design
- Performance Evaluation
- Conclusion

Flows and Coflows

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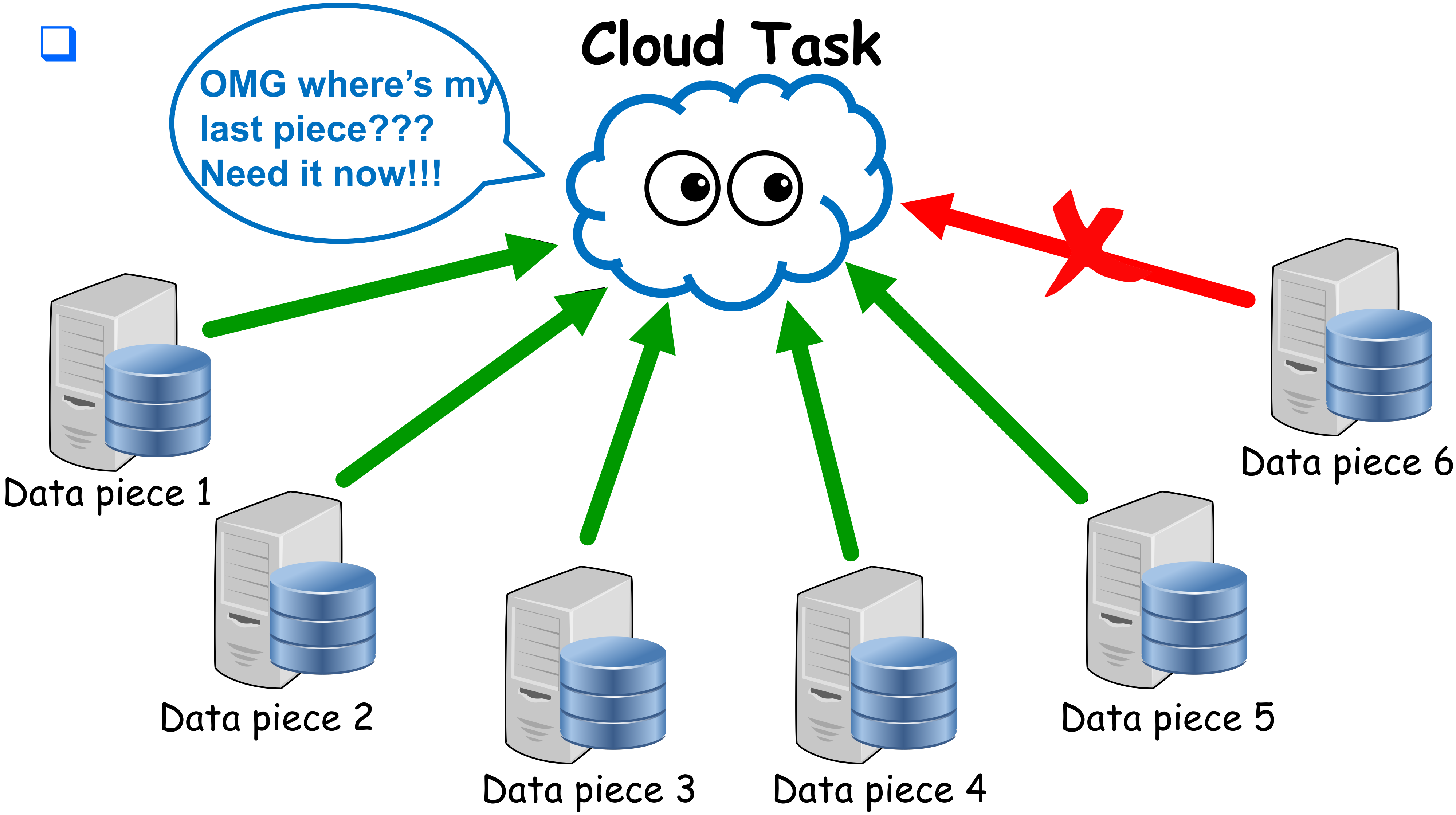
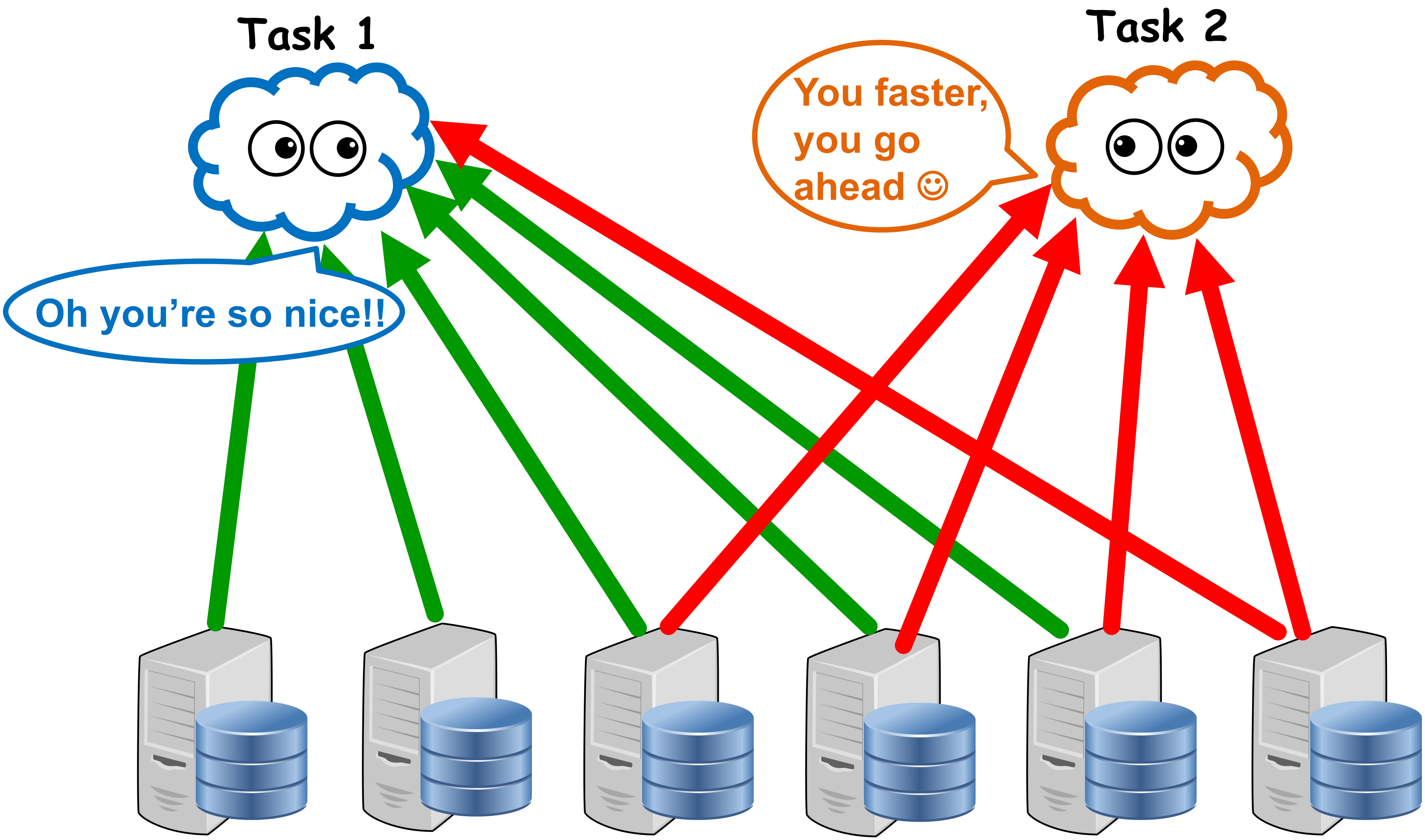


Flows and Coflows

- Traditional network scheduling/routing solution
  - Scheduling/Routing regarding **individual flows**
    - General flow: a subset of packet header fields
  - Fails to account for application-level performance metrics
    - **Flow completion time** vs. **task completion time**

Flows and Coflows



Flows and Coflows

- Application-aware scheduling/routing: coflows
  - Flows grouped by application/task
    - A coflow finishes when all its component flows finish
  - Advantages:
    - Captures application-level requirement
    - Establishes fairness in application-level
  - Want to do it in a centralized way
    - Not to **leak** app privacy to other apps
    - Or to prevent apps from **selfishly congest** the network

(Non-)Preemptive Scheduling

- Existing coflow scheduling/routing allows **preemption**!
  - Pause for the shorter ones!
  - Advantages:
    - Better performance and network utilization **in theory**
  - Disadvantages:
    - **Large overhead** for flow switching: performance issue for short flows
      - Switching delays
      - Switch computations
    - **No ready support** in commodity hardware
      - Standardization on-going: IEEE 802.1Qbu
      - A long way before commercial-ready
- Our stand: non-preemptive scheduling + routing of coflows

Summary of Problem

Contributions

- A first (preliminary) study for **Non-preemptive Coflow Scheduling and Routing (NCSR)**
- An offline scheduling framework: Shortest-Coflow First
- A multi-path routing algorithm
- A single-path routing algorithm
- Performance evaluations

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System Model

- Network: $G = (V, E)$
- Coflow requests: $S = \{C_1, \ldots, C_m\}$
  - Each request: $C_i = \{F_{i,1}, \ldots, F_{i,ni}\}$
  - $F_{i,j} = (s_{i,j}, t_{i,j}, d_{i,j})$: source, destination, flow size (demand, in bytes)
- Bandwidth allocation
  - $B^p{}_{i,j}(t)$: bandwidth allocation on path p of flow i, j, at time t
  - $B_{i,j}(t)$ = sum of bandwidth over all paths at time t

System Model

- Flow/coflow completion time

  - Flow completion time (FCT):

$$T_{i,j} = \arg\min_{\tau} \left\{ \int_0^{\tau} B_{i,j}(t)\, dt = d_{i,j} \right\}$$

  - Coflow completion time (CCT): max. FCT of its component flows

$$T_i = \max_j \{ T_{i,j} \mid F_{i,j} \in C_i \}$$

  - Objective: minimize total CCT

$$\min \quad \sum_{C_i \in S} T_i$$

Shortest-Coflow First Scheduler

- For each coflow:
  - Compute per-coflow completion time (CCT)
    - If multi-path enabled, compute using multi-path routing
    - Otherwise, use single-path routing
- Schedule coflows in ascending order of CCT

CCT with Multi-path Routing

- Non-linear programming formulation
  - Sharing among flows within the coflow
  - CCT as the maximum FCT of component flows

$$\min \quad \mathcal{T}_i \tag{6a}$$

$$\text{s.t.} \quad \mathcal{T}_i = \max_j \{d_{i,j}/b_{i,j}\} \tag{6b}$$

$$\sum_{j=1}^{n_i} f_{i,j}^e \le c_e \qquad \forall e \in E \tag{6c}$$

$$\sum_{(u,v)\in E} f_{i,j}^{(u,v)} - \sum_{(v,w)\in E} f_{i,j}^{(v,w)} = \begin{cases} 0\,, & v \notin \{s_{i,j}, t_{i,j}\} \\ -b_{i,j}\,, & v = s_{i,j} \\ b_{i,j}\,, & v = t_{i,j} \end{cases}$$
$$\forall F_{i,j} \in C_i, v \in V \tag{6d}$$

- Linearization: let $f_i = 1 \;/\; T_i$

$$\max \quad f_i \tag{7a}$$

$$\text{s.t.} \quad f_i \le b_{i,j}/d_{i,j} \qquad \forall F_{i,j} \in C_i \tag{7b}$$

(6c) and (6d)

CCT with Single-path Routing

- Additional integer variables to the Multi-path Routing model
  - $x^e_{i,j}$: link selection for single-path routing

- Linear relaxation and deterministic rounding
  - Relax $x^e_{i,j}$ to take continuous values, and solve linear program;
  - For each flow, find path with maximum minimum x values, and assign;
  - Re-solve program to obtain bandwidth allocation with fixed path assignments

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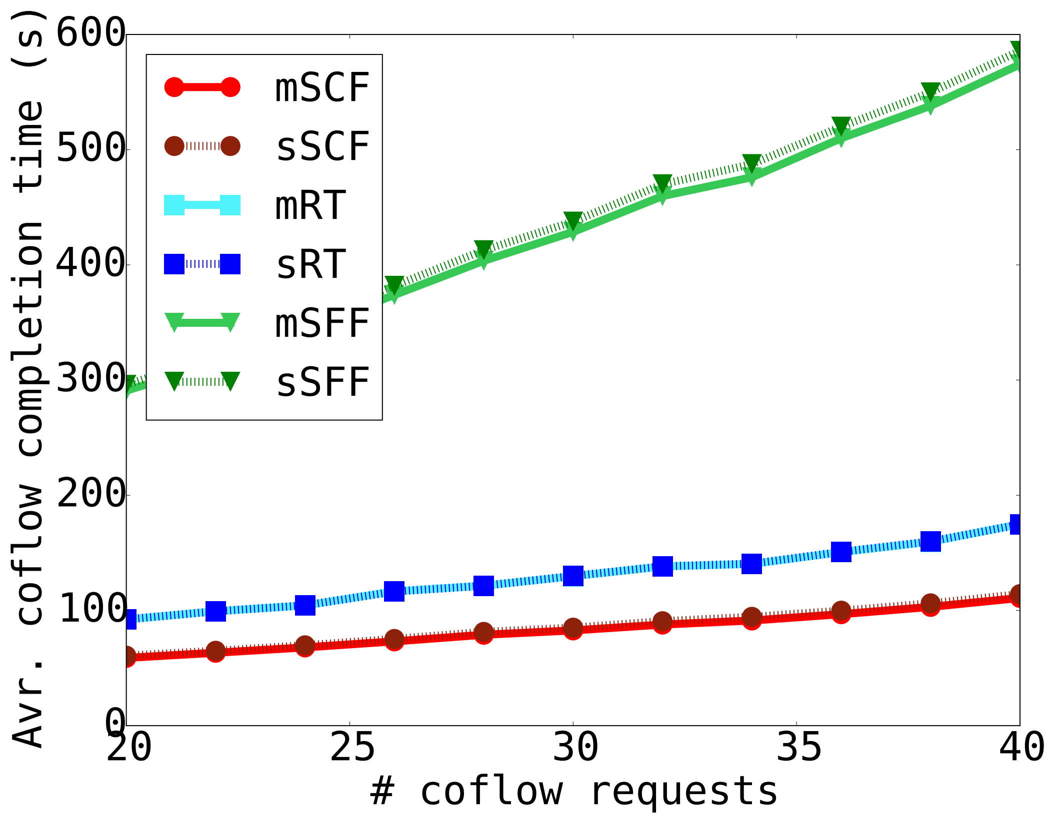
Simulation Setups

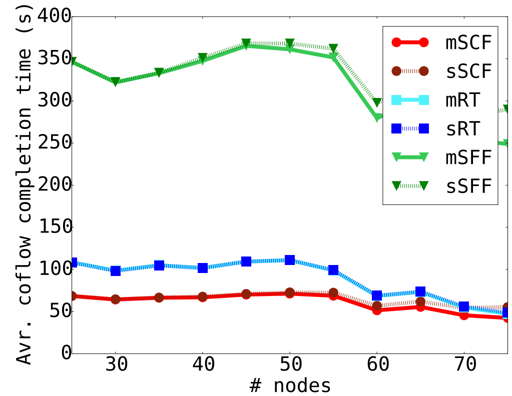
- Waxman random graphs
  - 50 nodes
  - Alpha=0.15, beta=0.2
  - Link capacities: [10, 100] Mbps

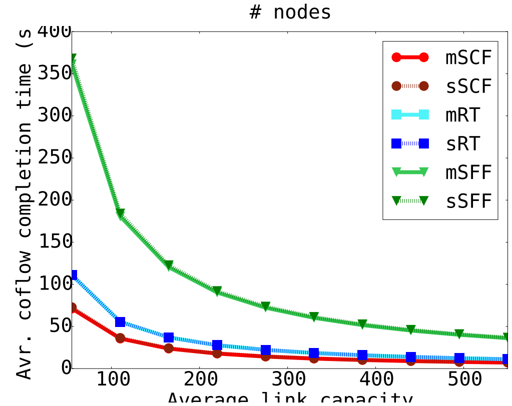
- Coflows
  - 25 requests
  - 1 to 10 flows per request
  - Flow sizes: [10, 100] Mbps

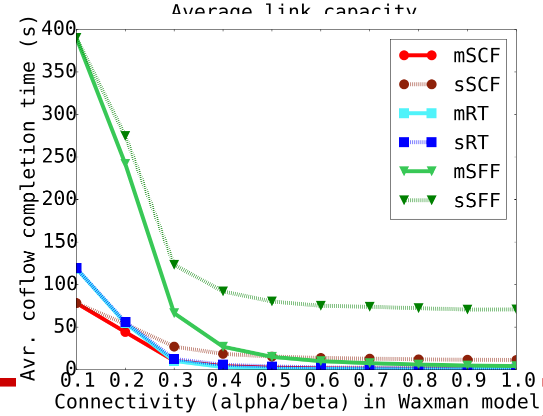
- Comparison:
  - sSCF, mSCF: single-path and multi-path SCF algorithm (proposed)
  - sRT, mRT: single-path and multi-path Routing-only algorithm (baseline)
  - sSFF, mSFF: single-path and multi-path Shortest-Flow First (baseline)

Simulation Results: Average CCT









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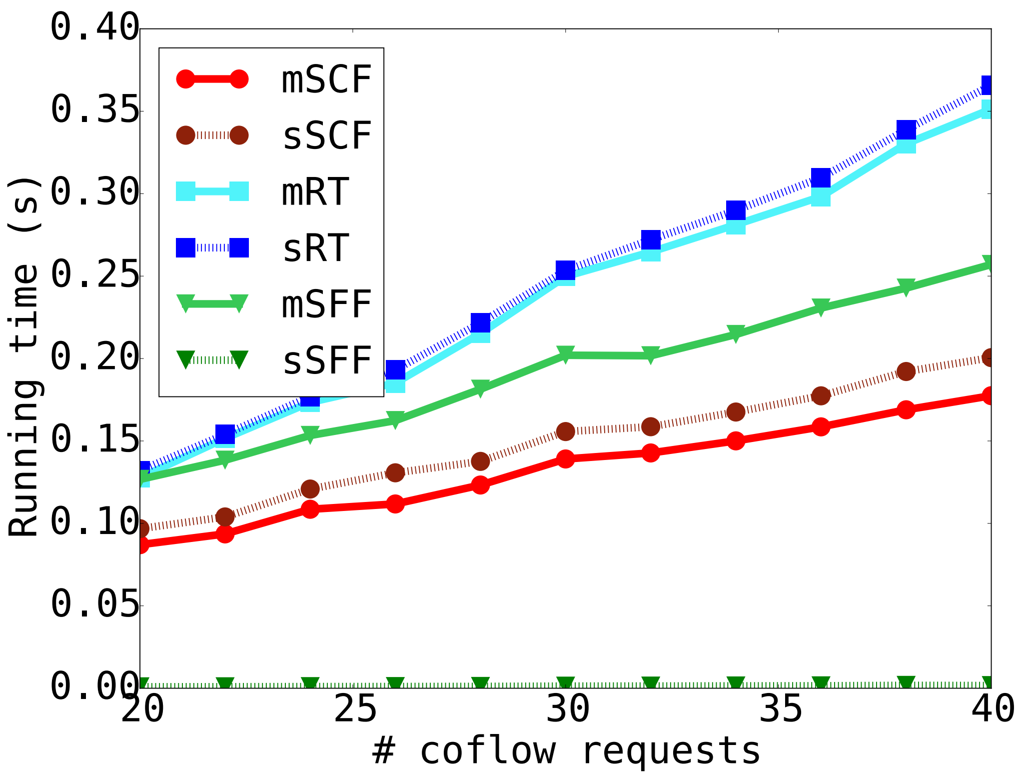
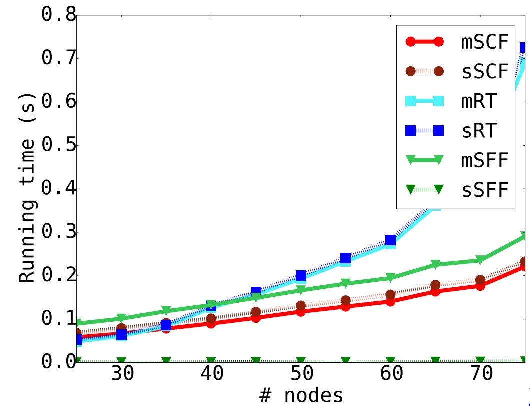
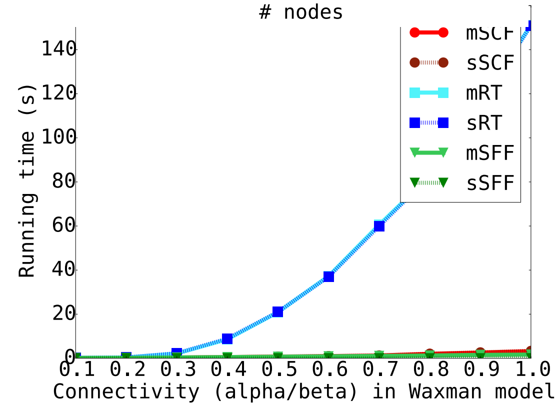
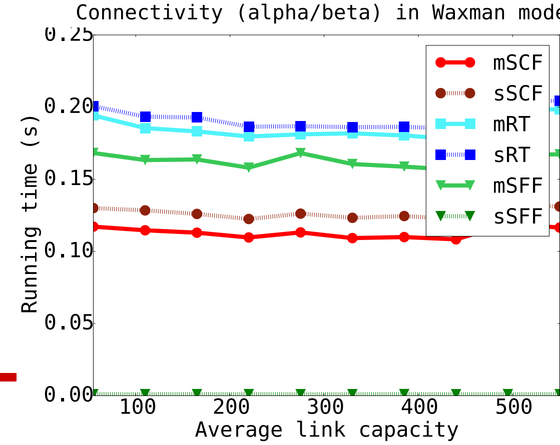
Simulation Results: Running Time









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Conclusions

- A first step study on NCSR
  - Offline optimization model
  - SCF scheduler for scheduling
  - Multi-path and single-path routing algorithms
- Experiment results
  - Scheduling more effective than routing: when network congested
  - Application-awareness brings great advantage
- Future work
  - Enable better sharing/work conservation of resources
    - Remove the non-sharing rule of coflows

Q&A?

THANK YOU VERY MUCH!