[Telecommunications Research Center Vienna]

Adaptive Multipath Routing for Dynamic Traffic Engineering

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Outline

- Introduction to traffic engineering
- Adaptive Multi-Path (AMP) algorithm
- Performance evaluation and results
- Summary and outlook

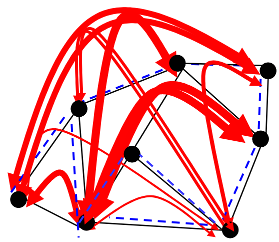
What is "Traffic Engineering" (TE)?

- Traffic engineering is defined as performance optimization of operational networks (IETF)
  - Consider the traffic at the macroscopic level
  - Consider the network as a set of *limited* resources
    - Transmission bandwidth, switching throughput
- Traffic engineering tries to optimally match **traffic demands** with the available **network** resources by acting on **routing**

Traffic Demands

Network

Routing

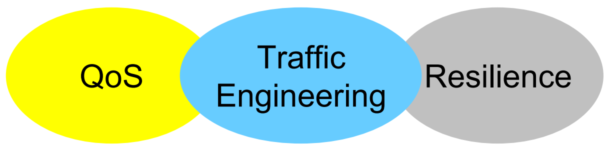


What can TE do, what not

- Objective: To balance the load in the network
  - Prevent mid-term congestion in the core
  - Increase the "effective capacity" of the network
  - Adapt to macroscopic changes in the traffic distribution (time scale: several minutes and above)
- What TE does not do:
  - Counteract congestion in the access links
  - Introduce service differentiation and/or guarantees (→ job for QoS mechanisms)
  - React to faults in the short-term (→ job for Resilience mechanisms)

Close friends of TE

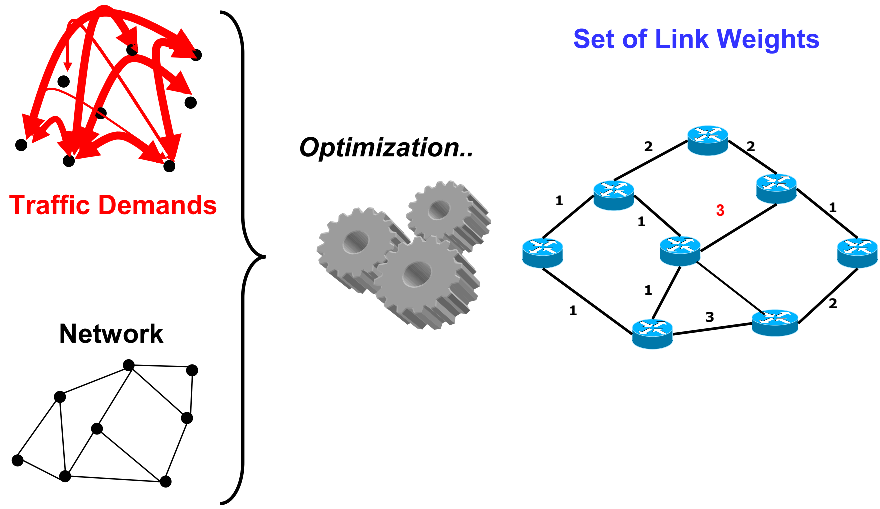
- By combating congestion TE indirectly improves the QoS
  - but TE is not a QoS mechanism
  - TE and QoS act at different levels and time-scales
  - Possible interaction: differentiated TE per QoS class
- TE hold strict relationships with resilience techniques
  - Fault isolation implies diverting traffic to another path



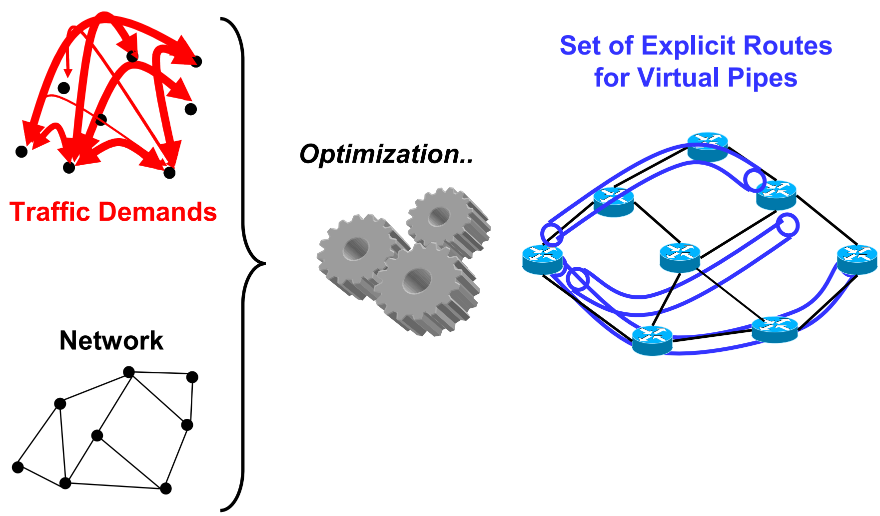
Traffic Engineering in IP Networks

- Traffic engineering methods for IP networks:
  - Link weight optimization in native IP networks
  - Optimization of Multi-Protocol Label Switched (MPLS) networks
  - Algorithmic approaches (dynamic routing in the ARPAnet, OMP)

Example of Connection-Less TE: Link Weight Optimization



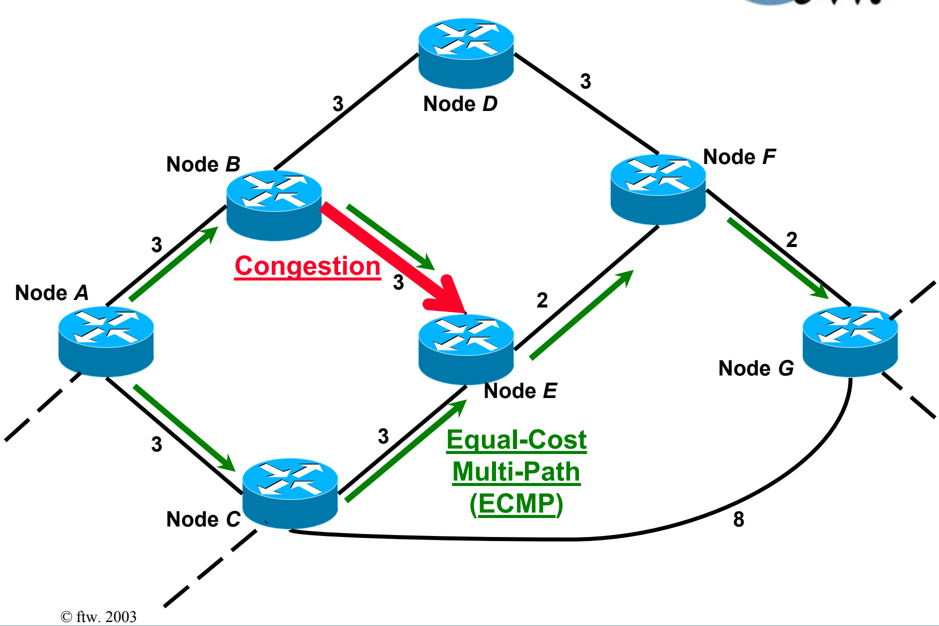
Example of Connection-Oriented TE: Explicit-Routing Optimization



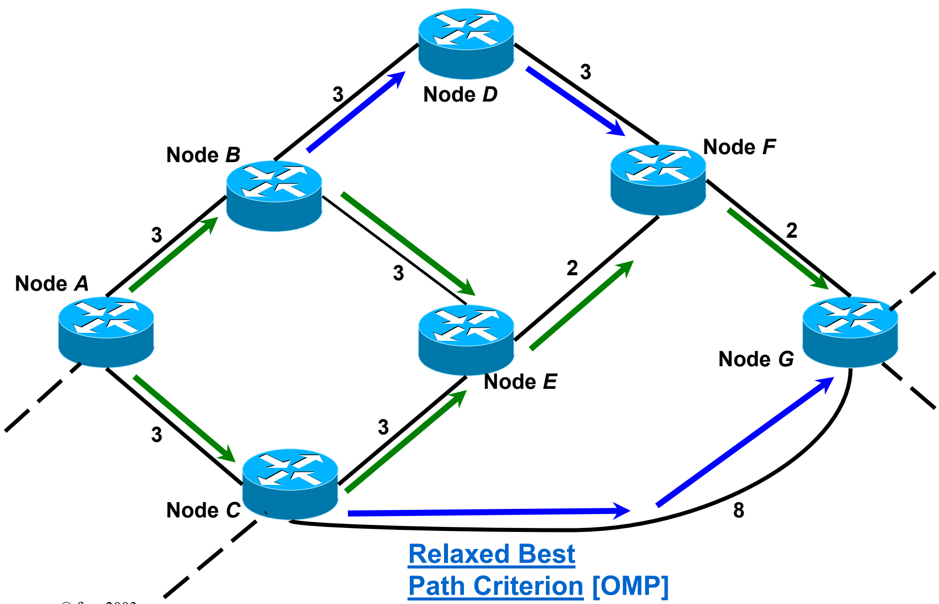
Traffic Engineering in IP Networks

- Existing traffic engineering methods have important disadvantages:
  - MPLS and *link weight optimization* require additional network management
  - Unpredictable signaling overhead with Optimized Multi-Path (OMP)
- Our objective:
  - Autonomous and continuous load distribution in the network
  - Low overhead in terms of memory and bandwidth consumption
- Proposal: Adaptive Multi-Path Algorithm (AMP)

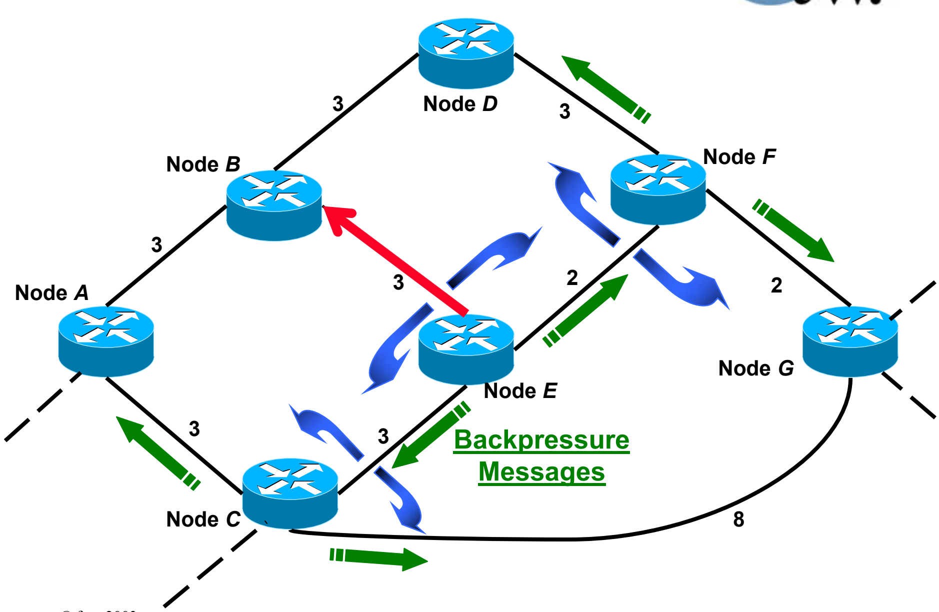
Adaptive Multi-Path (AMP)



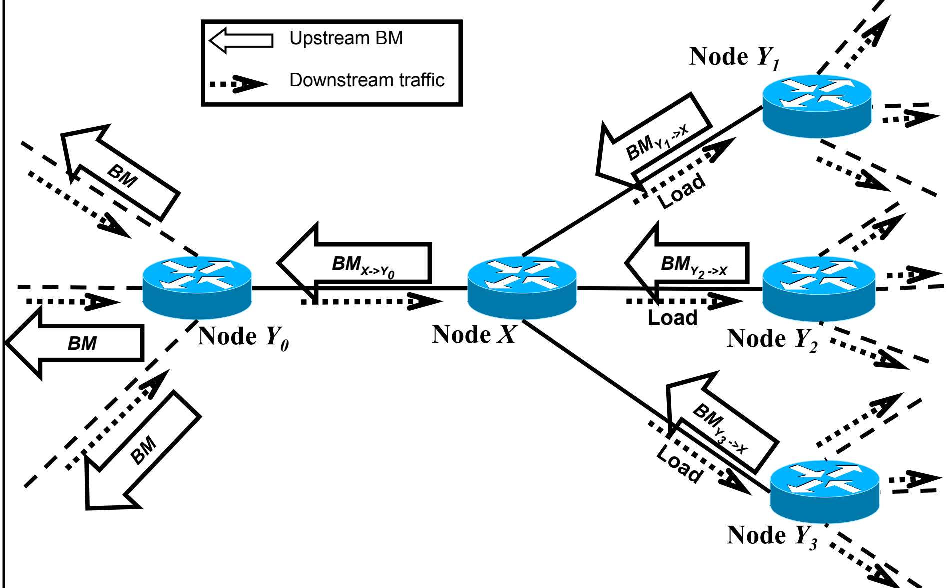
AMP – Choice of Multiple Paths



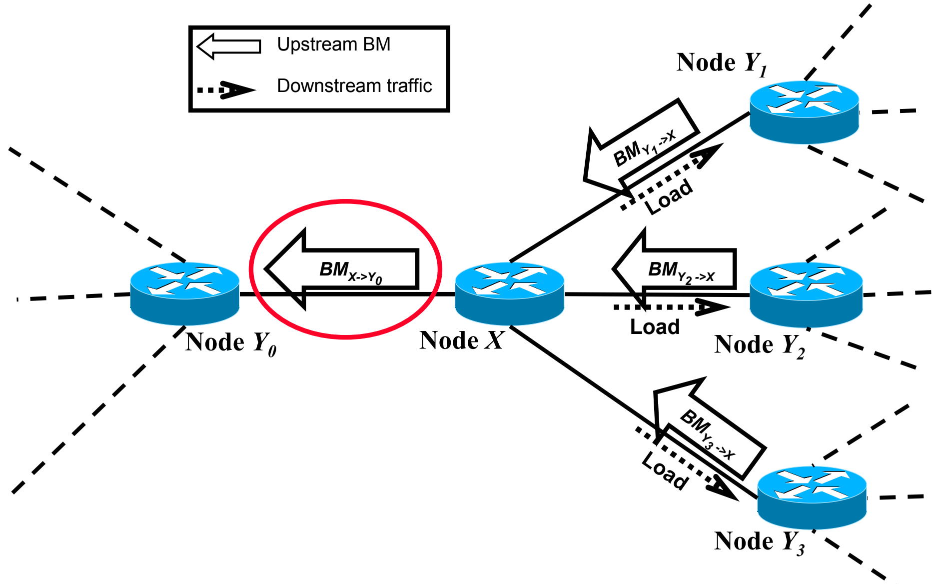
AMP – Basic Operation



AMP – Signaling



AMP – Signaling



AMP – Signaling

$$BM_{X->Y_0} = f(Load_{\overline{XY_1}}, ..., Load_{\overline{XY_n}}, BM_{Y_1->X}, ..., BM_{Y_n->X})$$

Quasi-recursive structure of backpressure messages

⇨

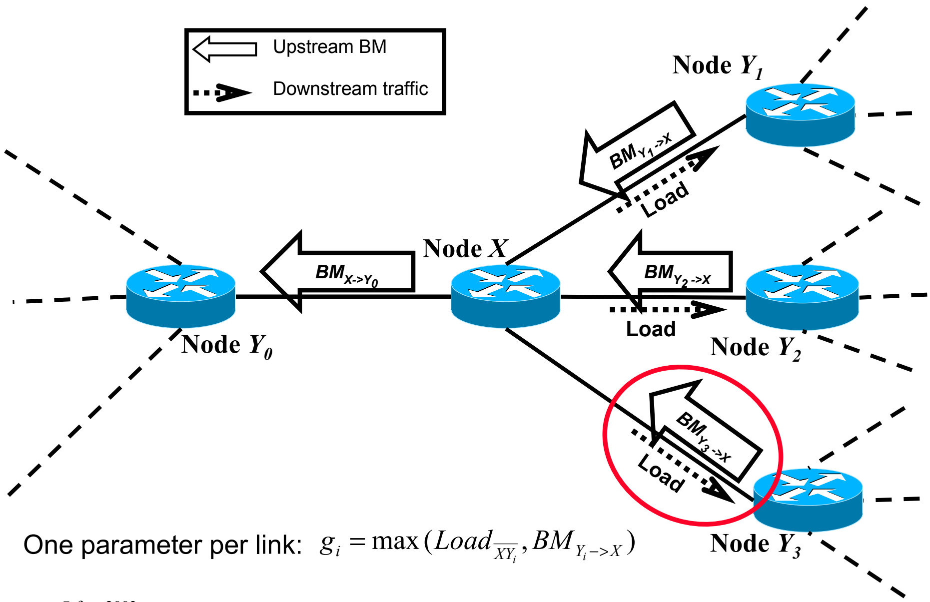
GLOBAL PROPAGATION OF LOAD INFORMATION THROUGH LOCAL EXCHANGE OF SIGNALING MESSAGES

AMP – Signaling

$$BM_{X->Y_0} = f(Load_{\overline{XY_1}}, ..., Load_{\overline{XY_n}}, BM_{Y_1->X}, ..., BM_{Y_n->X})$$

⇩ Summarization of the number of parameters

AMP – Signaling



One parameter per link: $g_i = \max(Load_{\overline{XY_i}}, BM_{Y_i->X})$

AMP – Signaling

$$BM_{X->Y_0} = f(Load_{\overline{XY_1}}, \ldots, Load_{\overline{XY_n}}, BM_{Y_1->X}, \ldots, BM_{Y_n->X})$$

⇩ Reduction of the number of parameters

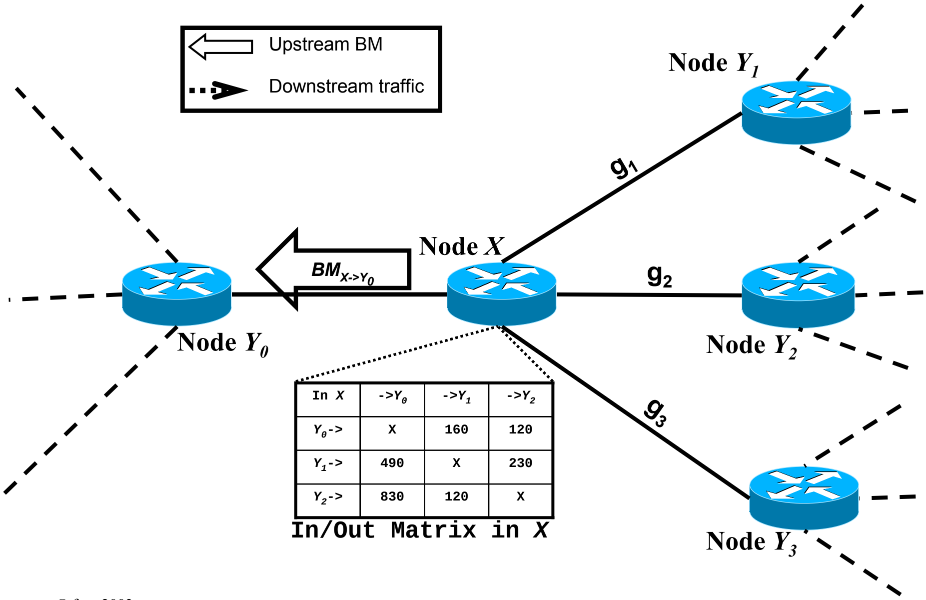
$$g_i = \max(Load_{\overline{XY_i}}, BM_{Y_i->X})$$

⇩

$$BM_{X->Y_0} = f(g_1, g_2, \ldots, g_n)$$

?

AMP – Signaling



In X	->Y_0	->Y_1	->Y_2
Y_0->	X	160	120
Y_1->	490	X	230
Y_2->	830	120	X

In/Out Matrix in X

AMP – Signaling

$$BM_{X->Y_0} = f(Load_{\overline{XY_1}}, \ldots, Load_{\overline{XY_n}}, BM_{Y_1->X}, \ldots, BM_{Y_n->X})$$

⇩ Reduction of the number of parameters

$$g_i = \max(Load_{\overline{XY_i}}, BM_{Y_i->X})$$

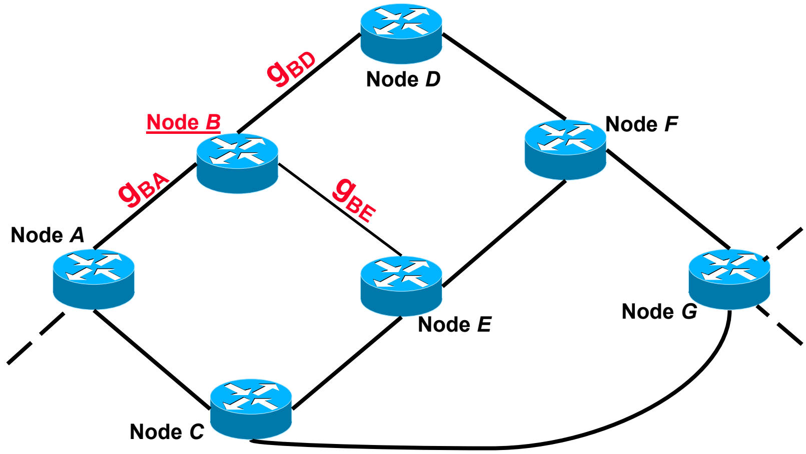
⇩

$$BM_{X->Y_0} = f(g_1, g_2, \ldots, g_n)$$

$$= \sum_{Y_i \in \Omega_X \setminus Y_0} \frac{\beta_{\overline{Y_0 X Y_i}}}{\beta_{\overline{X Y_i}}} \cdot g_i$$

weights for congestion contributions

AMP – Load Balancing



- The goal of the load balancing mechanism in every node is to equalize the values of g on all output links

AMP – Load Balancing

- In order to avoid packet disordering:
  - => the unit for load balancing is a microflow aggregate
  - => packets are assigned to an aggregate by applying a *CRC-16* hash-function on their source and destination IP addresses
- The *CRC-16* solution space [0, 65535] is divided among the viable next hops

161.53.101.8
173.42.78.55 } **CRC-16** => 13217

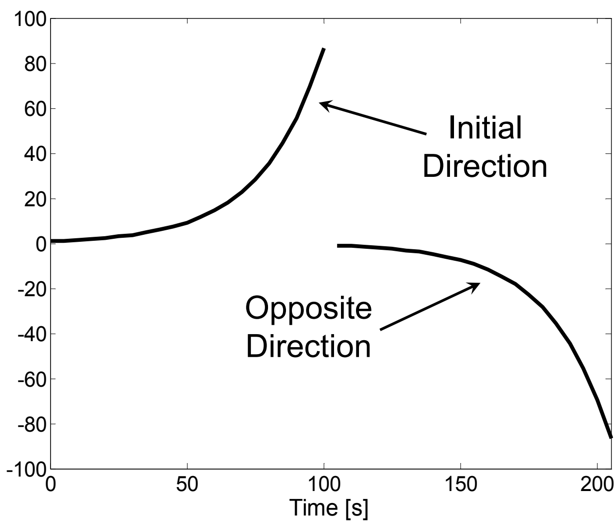
AMP – Load Balancing

- Example routing table in Node *B* – the hash-space boundaries are defined for every reachable destination

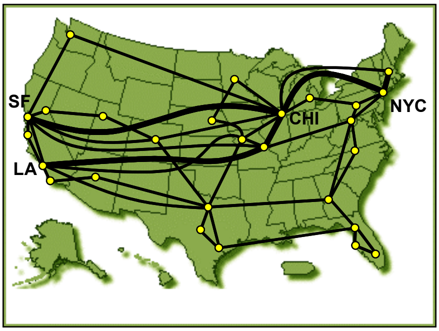
Destinations (in Node B)	Next hop: Node *A*	Next hop: Node *D*	Next hop: Node *E*
Node *A*	[0 – 65535] (ALL PACKETS)		
Node *C*	[0 – 23723]		[23724 – 65535]
Node *D*		[0 – 65535] (ALL PACKETS)	
Node *E*			[0 – 65535] (ALL PACKETS)
Node *F*		[0 – 34447]	[34448 – 65535]
Node *G*		[0 – 52142]	[52143 – 65535]

AMP – Load Balancing

- Conservative load balancing mechanism – the size of load adjustment steps is changed dynamically

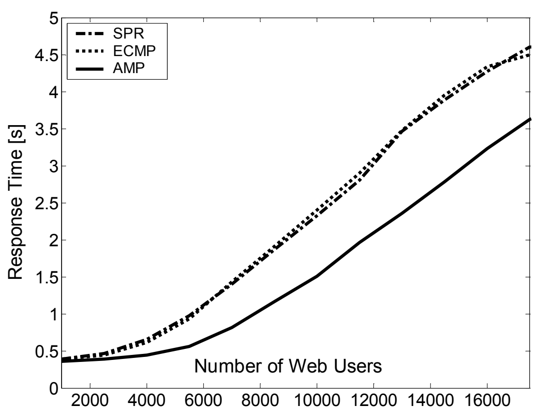


AMP Performance Evaluation



- Implementation of AMP in Network Simulator (ns-2)
- Simulated topology:
  - AT&T-US Network of 27 nodes and 47 links
  - Link capacities of 2.4 and 9.6 Gbit/s (scaled down to 15 and 60 Mbit/s in our simulations)
- Simulated traffic:
  - Web traffic according SURGE model
  - Traffic distribution according to the gravity model
  - Linear scaling of the number of Web users

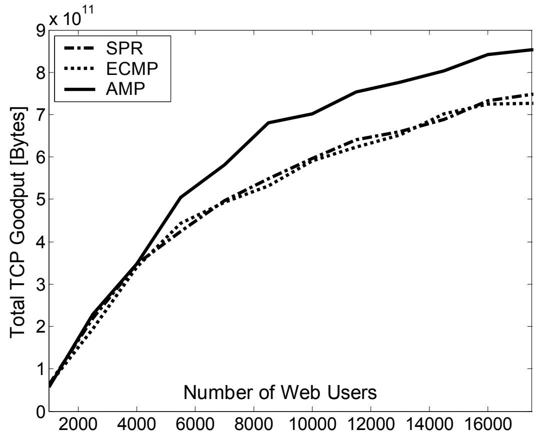
AMP Performance Evaluation – Average Web Page Response Time



- Web page response time most important metric from the user´s perspective
- Significant reductions in Web page response times throughout investigated scenarios (up to 43%)

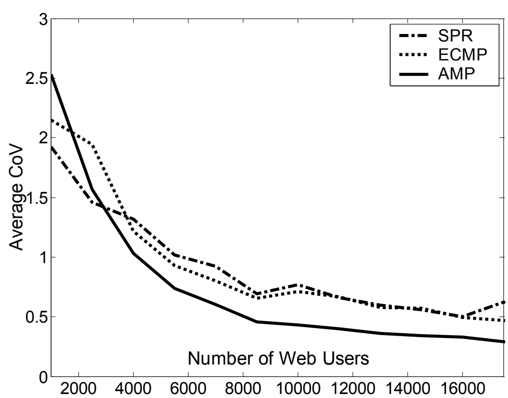
- SPR– Shortest Path Routing
- ECMP – Equal-Cost Multi-Path Routing

AMP Performance Evaluation – Total TCP Goodput



- Improved efficiency of resource utilization
- Total TCP goodput consistently higher with AMP compared to SPR and ECMP in our simulations (improvements of up to 28%)

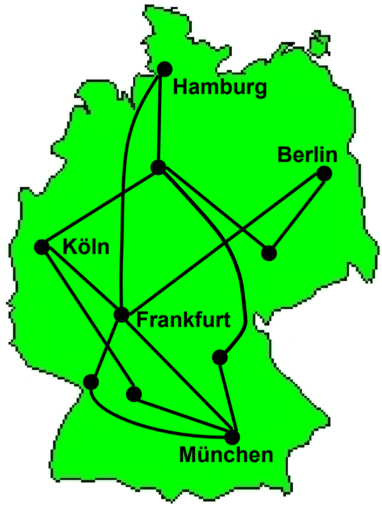
AMP Performance Evaluation – Average CoVs of Link Load



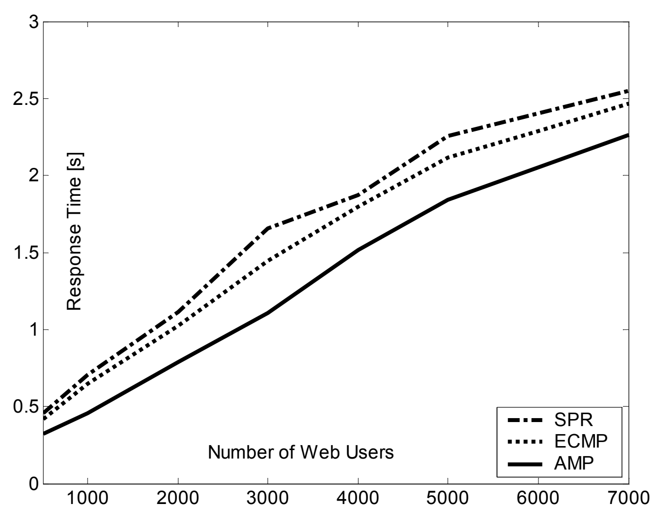
- Similar average Coefficient of Variation (CoVs) of all link loads for the three routing strategies

  $\Rightarrow$ stability of AMP load balancing

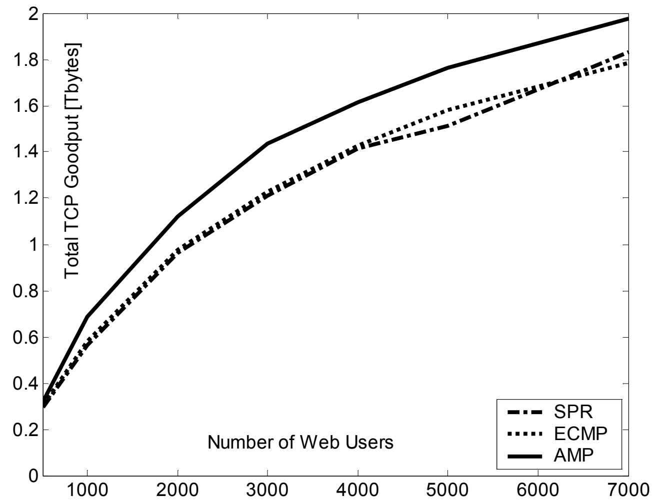
AMP Performance Evaluation



AMP Performance Evaluation – Average Web Page Response Time



AMP Performance Evaluation – Total TCP Goodput



Publications

- I. Gojmerac, T. Ziegler, P. Reichl: *Adaptive Multipath Routing Based on Local Distribution of Link Load Information*. Proc. QoFIS'03, Stockholm, October 2003.
- I. Gojmerac, T. Ziegler, F. Ricciato, P. Reichl: *Adaptive Multipath Routing for Dynamic Traffic Engineering*. Proc. GLOBECOM'03, San Francisco, November 2003.

Summary & Outlook

- AMP Summary:
  - Load balancing within the framework of routing
  - No management overhead, minimal signaling overhead
  - Implementation in Network Simulator (ns-2)
  - Significant performance improvements
- Future research:
  - AMP and network resilience

Thank you for your attention!