

Simplicity in Complex Networks

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Networking Research Needs More Funding

Is networking so successful that further government investment in its research has reached the point of diminishing marginal return?

No, because:

Practical reasons:

- Anytime, anywhere, any content, any person: remains a **distant goal**
- **US lags behind** Europe and Asia in ubiquitous, open access

Intellectual reason:

- Internet increasingly **uncontrollable and unpredictable**
- Can network engineering be based on **science**?

Science Part of FIND

- Human memory is too limited:

Can't afford to **describe** each protocol and system

Need simple, **explanatory** models

Analogy: transform from 19th century to 21st century biology

- Human lifespan is too short:

Can't afford to design based on **trial and error** tuning of parameters

Need to **derive** future design

Theories not just as problem-solvers, but disruptively **re-organizes the human engineering process**: start from first principle and produce engineering artifacts as derived consequences

Three Viewpoints of Simplicity

Simple Description:

- From Descriptive to Explanatory Models

Simple Conceptual Framework:

- From Describing to Deriving Architectures
- Robustness to Network Dynamics

Simple Protocols:

- Tradeoff with Complexity
- Design for Optimizability

Making a difference in large-scale operational networks

1. From Descriptive to Explanatory

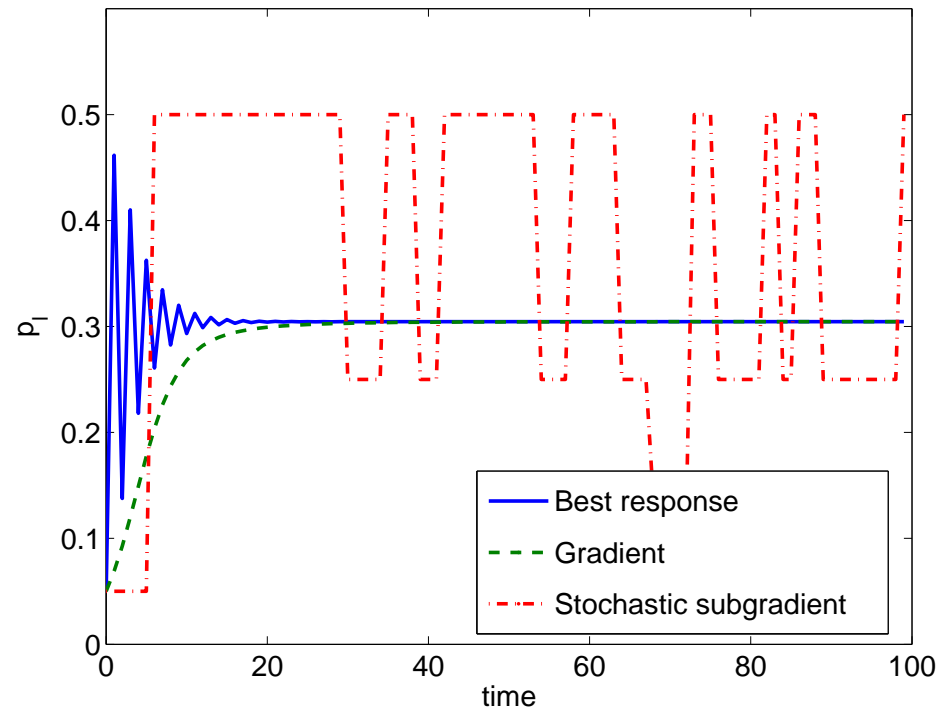
Current status of reverse-engineering:

- TCP congestion control:
implicitly solves the basic **Network Utility Maximization**
- Inter-AS routing:
implicitly solves **Stable Paths Problem**
- Random access contention resolution:
implicitly participates in **MAC-Game**

Puts networking on the same level of intellectual foundation as Physical Layer on information theory

1. Networking as Distributed Computation

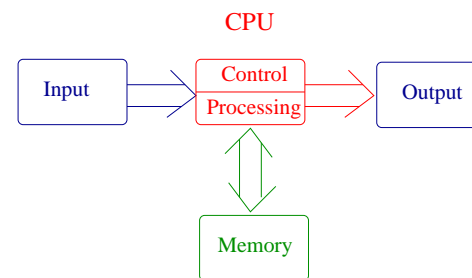
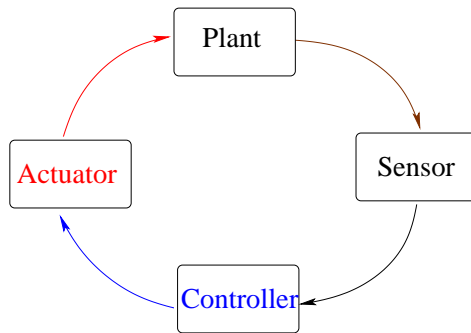
Reverse engineer backoff MAC as a non-cooperative game



J. W. Lee, A. Tang, J. Huang, M. Chiang, and A. R. Calderbank, "Reverse engineering MAC: A game-theoretic model", *IEEE Journal of Selected Areas in Communication*, Jul. 2007

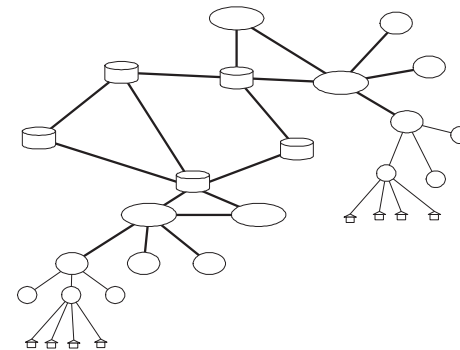
2A. Architecture: Functionality Allocation

Architectures well-understood in control and computation



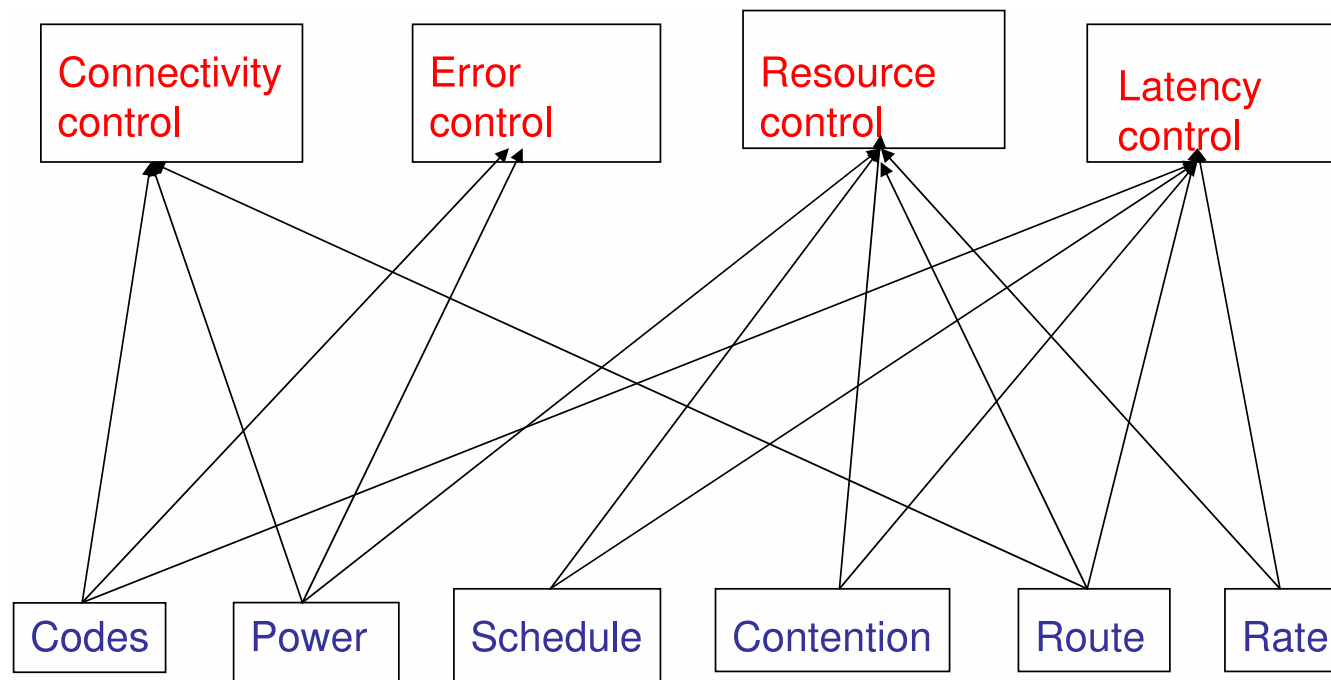
What about network architecture?

Application
Presentation
Session
Transport
Network
Link
Physical



2A. Math Foundation for Network Architecture

Who should do what and how to connect them



M. Chiang, S. H. Low, A. R. Calderbank, and J. C. Doyle, "Layering as optimization decomposition: A mathematical theory of network architectures", Proceedings of the IEEE, Jan. 2007

2A. Layering As Optimization Decomposition

Network: Generalized NUM

Layering architecture: Decomposition scheme

Layers: Decomposed subproblems

Interfaces: Functions of primal or dual variables

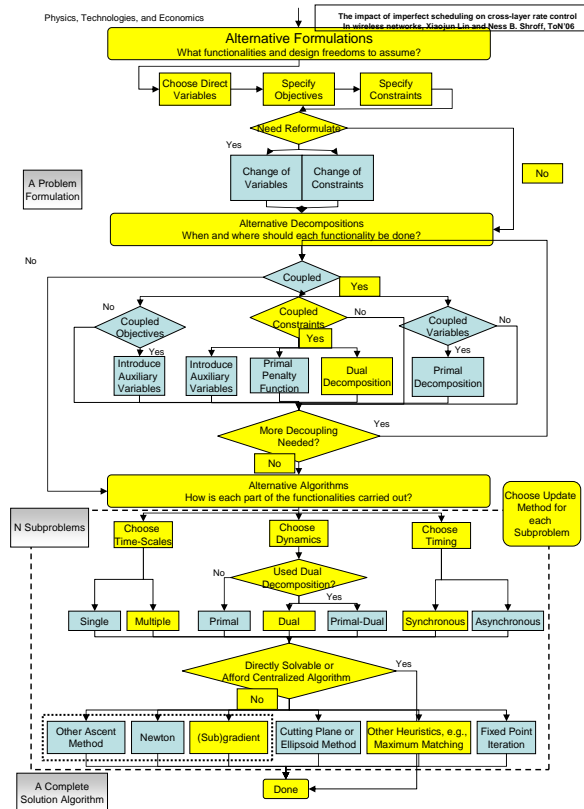
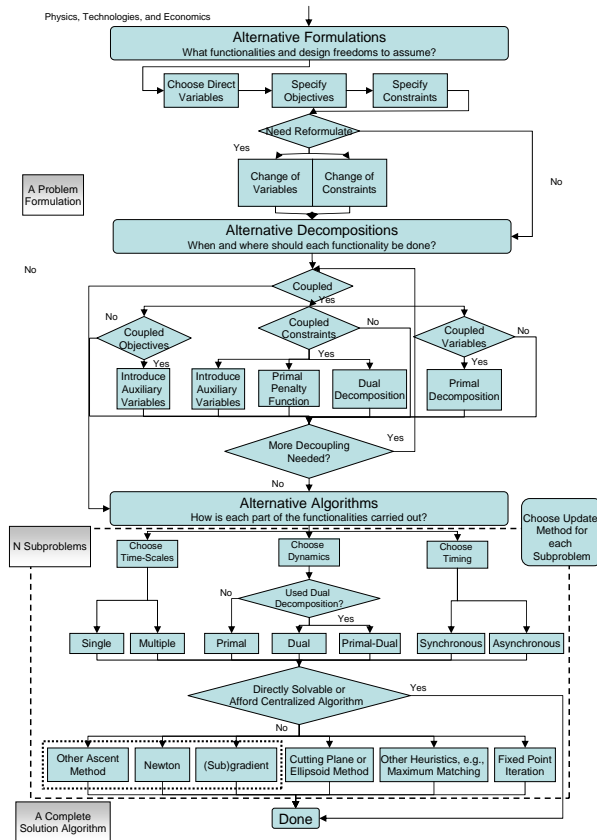
Horizontal and vertical decompositions through

- implicit message passing (e.g., queuing delay, SIR)
- explicit message passing (local or global)

3 Steps: G.NUM \Rightarrow A solution architecture \Rightarrow Alternative architectures

2A. Unifying Framework Trims Knowledge Tree

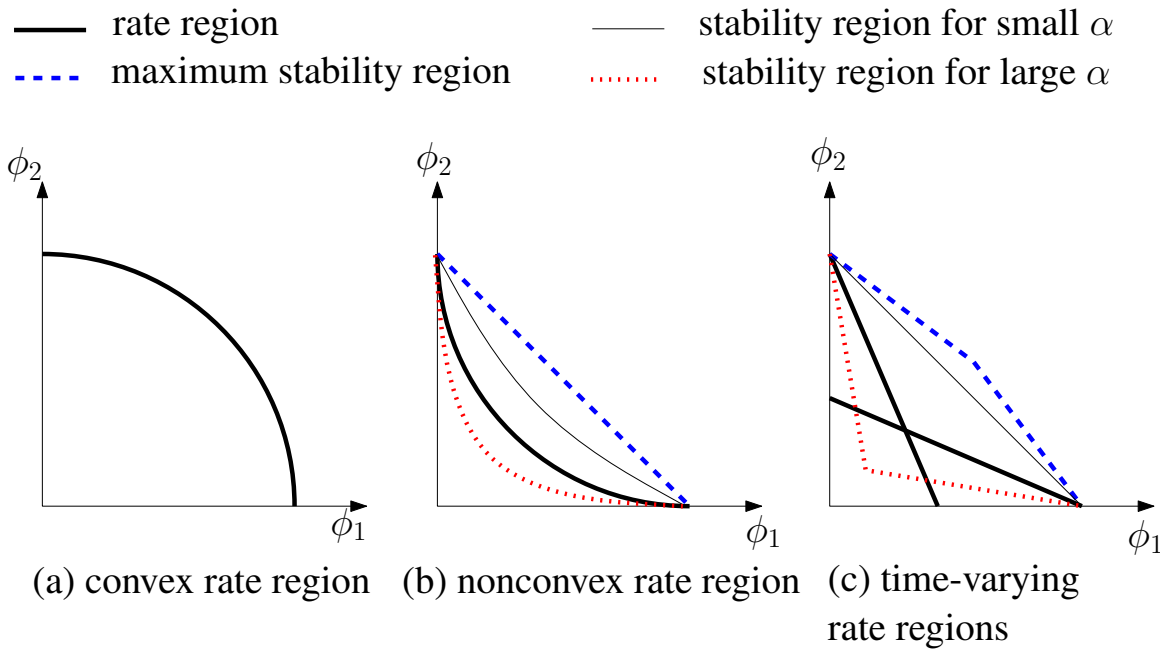
Many cross-layer papers as special cases of 1 workflow



D. Palomar and M. Chiang, "Alternative distributed algorithms for network utility maximization: Framework and applications", *IEEE Transactions on Automatic Control*, Dec. 2007

2B. Robustness I: Stochastic NUM

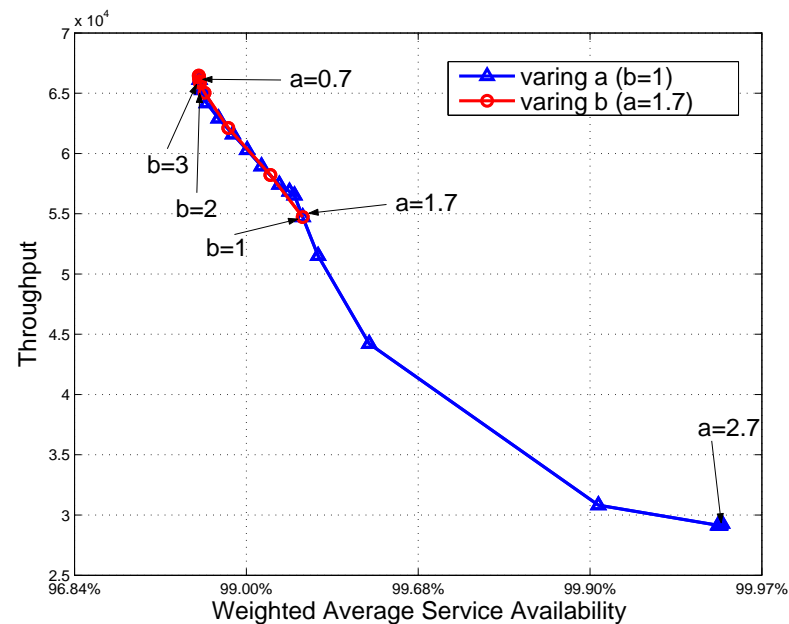
Stochastic dynamics at session, packet, and constraint levels



Y. Yi and M. Chiang, "Stochastic network utility maximization: A tribute to Kelly's paper published in this journal a decade ago", *European Transactions on Telecommunications*, March 2008

2B. Robustness II: NUM for Availability

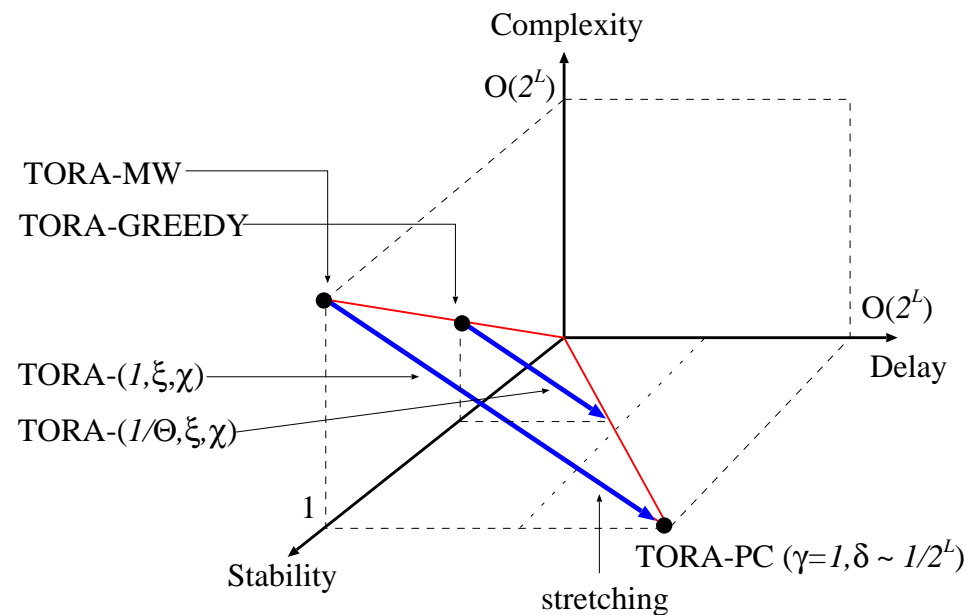
Quantify tradeoff: normal-time throughput and down-time availability



D. Xu, Y. Li, M. Chiang, and A. R. Calderbank, "Elastic service availability: Utility framework and optimal provisioning", *IEEE Journal of Selected Areas in Communications*, 2008

3A. Tradeoff with Complexity: Wireless Scheduling

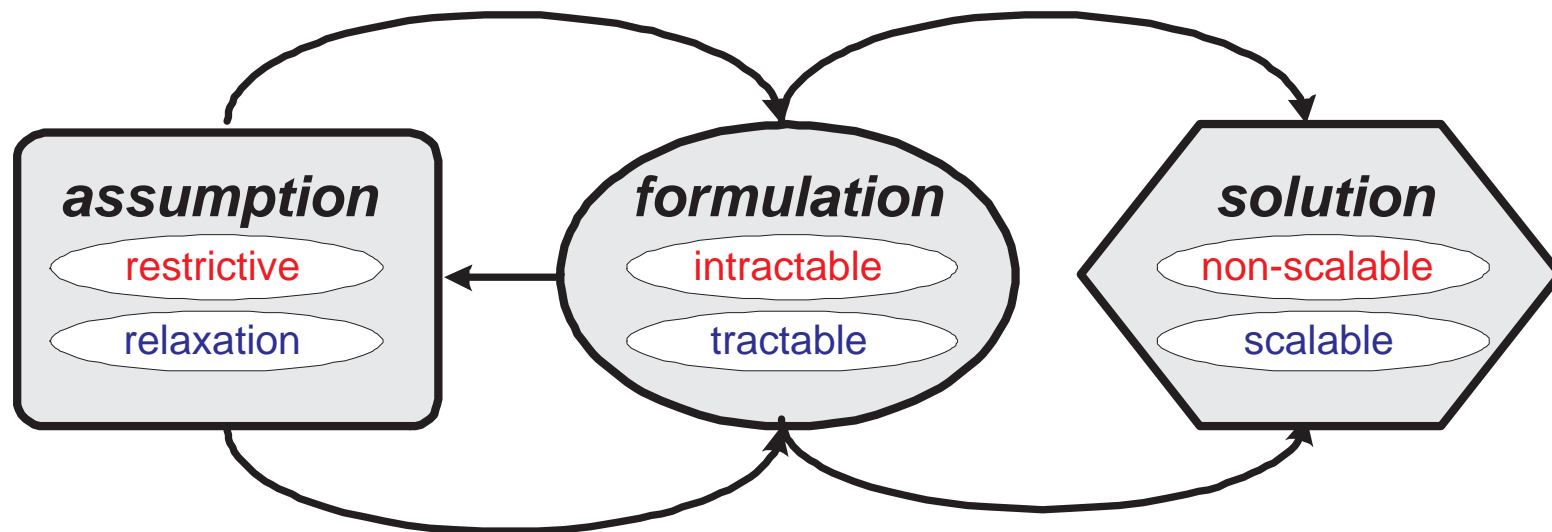
3D throughput-delay-complexity tradeoff in a parameterized framework



Y. Yi, A. Proutiere, and M. Chiang, "Complexity-stability-delay tradeoff in scheduling over wireless networks", *ACM Mobihoc*, May 2008

3B. Design for Optimizability (DFO)

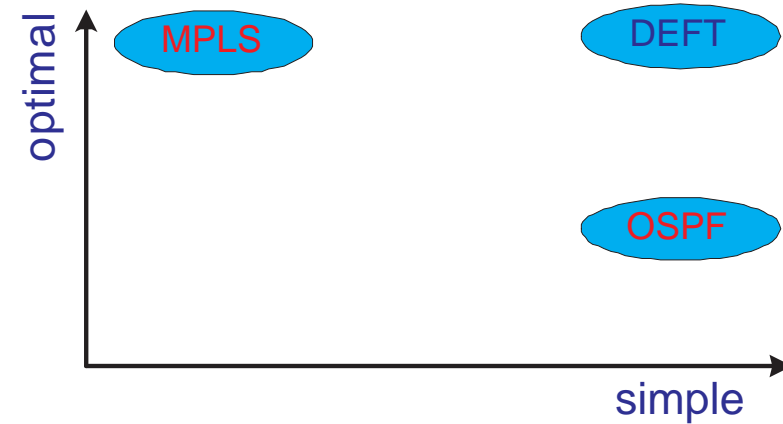
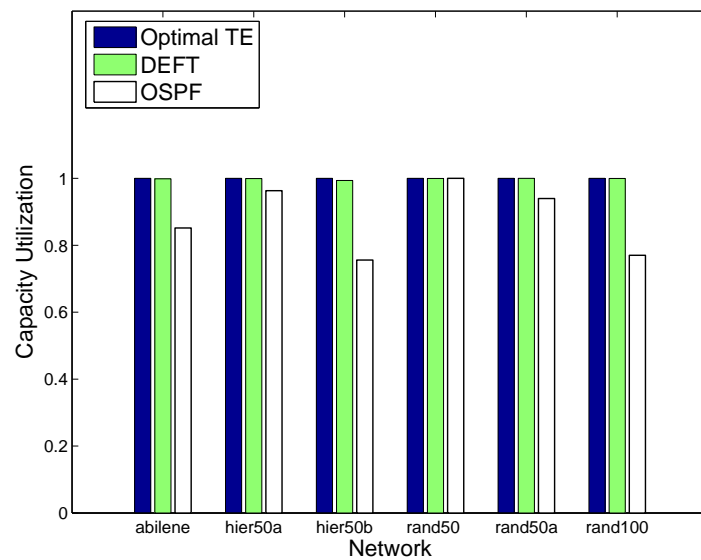
Adding feedback in network engineering workflow



J. He, J. Rexford, and M. Chiang, "Don't optimize existing protocols, design optimizable protocols", *ACM Sigcomm Computer Communications Review*, Aug. 2007

3B. DFO at Work: Internet Routing

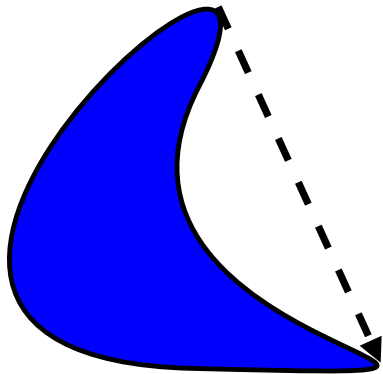
Simple distributed routing achieves optimal Internet traffic engineering



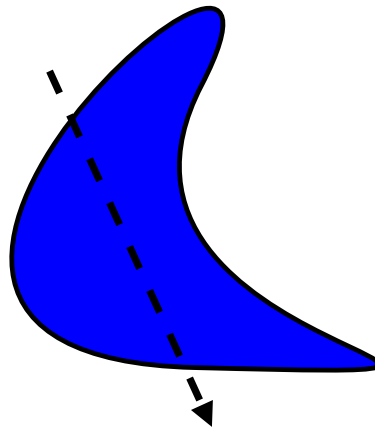
D. Xu, M. Chiang, and J. Rexford, "Link-state routing with hop-by-hop forwarding achieves optimal traffic engineering", *IEEE INFOCOM*, 2008

3B. Geometry of Simplicity

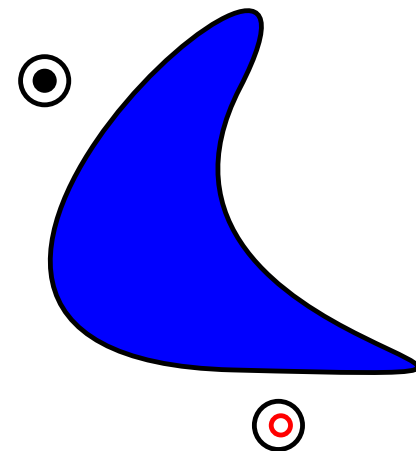
Going "Around", "Through", or "Above" Nonconvexity



1



2



3

M. Chiang, "Nonconvex optimization of communication systems", *Advances in Mechanics and Mathematics, Special Volume on G. Strang's 70th Birthday*, Ed., D. Gao and H. Sherali, Springer, 2008

Impact on Operational Networks

- Wireline Broadband Access

FAST Copper Project: With **AT&T** and **Marvell**

- Wireless Broadband Access

Load-spillage power control: With **Qualcomm** and **Siemens-Nokia**

- Internet Virtualization

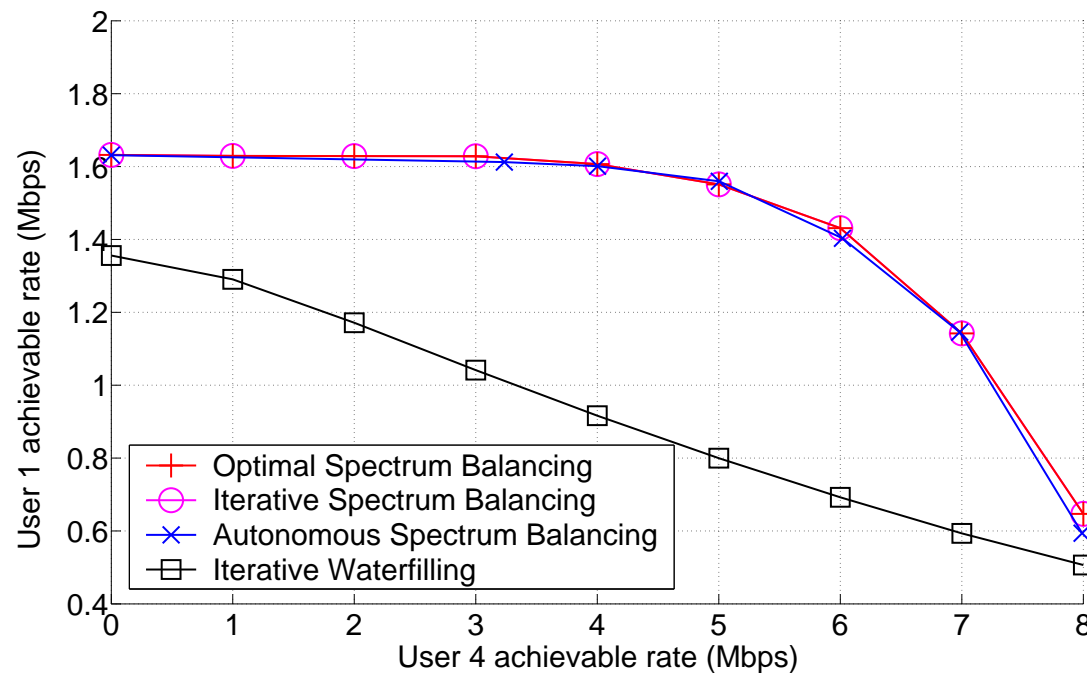
DEFT and adaptive virtualization: With **AT&T** and **Cisco**

- Content Distribution

ISP-CDN-P2P interaction and pricing: With **Microsoft** and **Motorola**

Tech Transfer: Wireline Broadband Access

Power allocation over multi-carrier interference channel of DSL



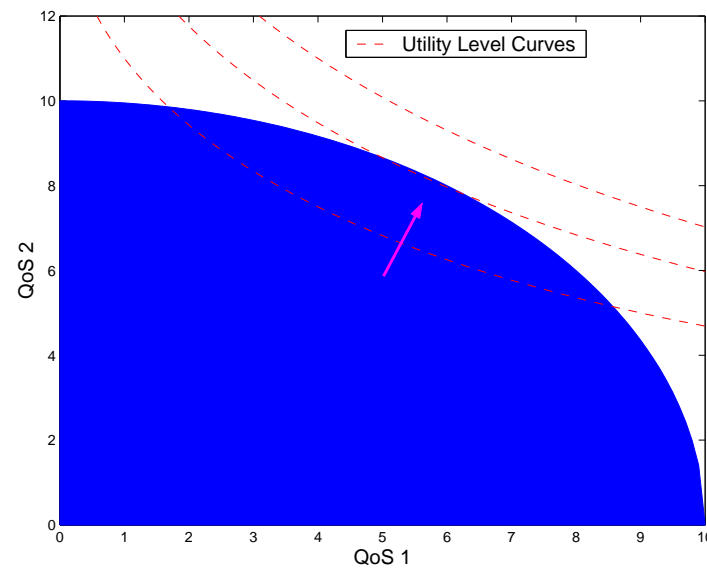
R. Cendrillon, J. Huang, M. Chiang, and M. Moonen, "Autonomous Spectrum Balancing for Digital Subscriber Lines", *IEEE Transactions on Signal Processing*, Aug. 2007

Tech Transfer: Wireless Broadband Access

Maximize: utility function of powers and SIR assignments

Subject to: SIR assignments feasible

Variables: **transmit powers and SIR assignments**



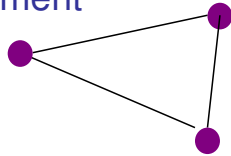
P. Hande, S. Rangan, M. Chiang, and X. Wu, "Distributed uplink power control for optimal SIR assignment in cellular data networks", *IEEE/ACM Transactions on Networking*, 2008

Industry Collaboration: Adaptive Virtualization

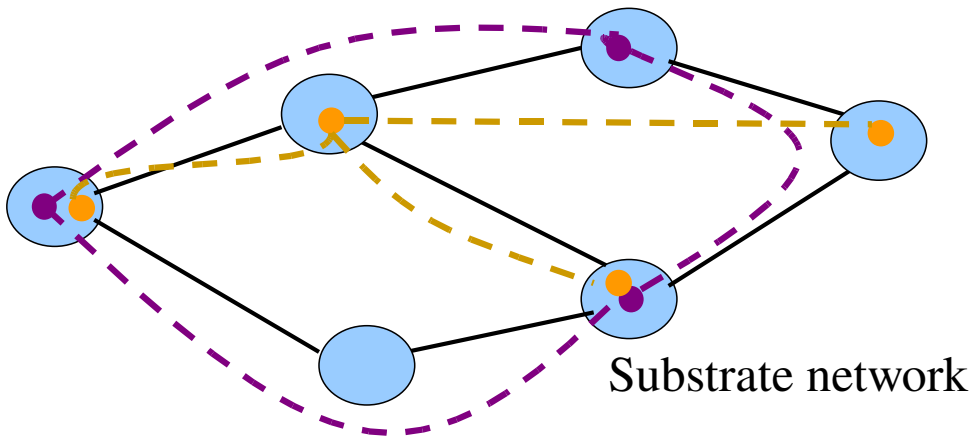
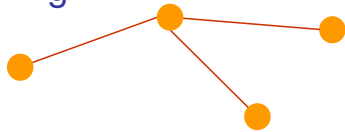
Adaptive slicing in network virtualization by primal decomposition

Virtual networks

experiment



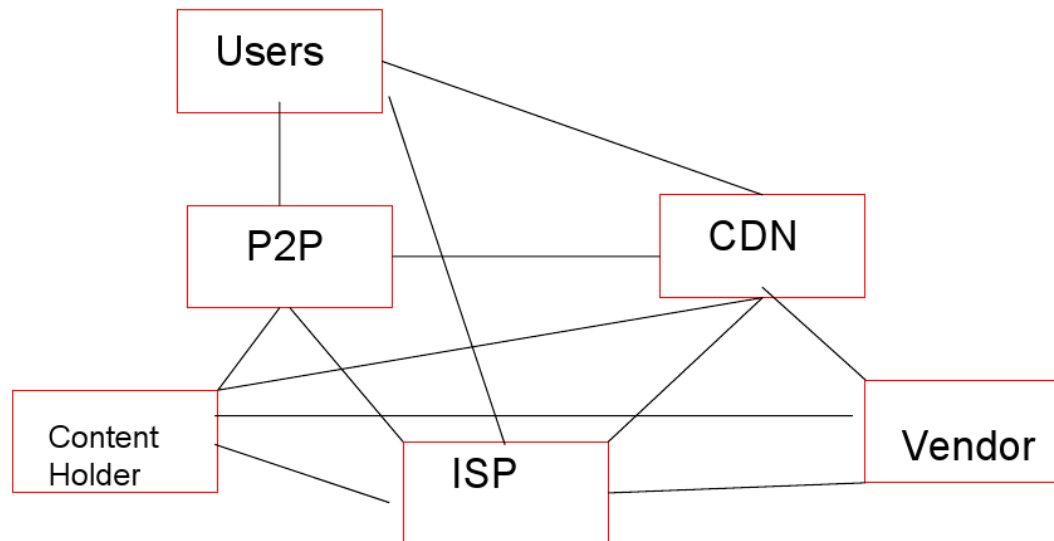
gaming



J. He, R. Zhang-Shen, Y. Li, C. Y. Lee, J. Rexford, and M. Chiang, "DaVinci: Dynamically adaptive virtual network for customized Internet", *Proc. ACM CoNEXT*, December 2008.

Industry Collaboration: Content Distribution

Bridging the Content-Pipe Divide



W. Jiang, R. Zhang-Shen, J. Rexford, and M. Chiang, "Cooperative content distribution and traffic engineering in an ISP network", *ACM Sigmetrics*, June 2009

Contacts

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