Measurement-Based Multicast on Overlay Architecture

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LTS Review

June 18th, 2004

Outline

- Multi-path Multicast Routing
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Introduction

- Intra-domain multicast routing
  - Highly connected ISP backbone topologies.
    - N. Spring, R. Mahajan and D. Wetherall
      “Measuring ISP topologies with Rocketfuel”, Sigcomm 2002
    - Existence of multiple paths
  - Traffic engineering point of view:
    - Load balancing over multiple paths for efficient network utilization
    - Extending ideas from multi-path unicast routing
  - Our goal:
    - Multi-path multicast routing algorithms using (i) an overlay architecture and (ii) noisy measurement

Introduction - cont’d

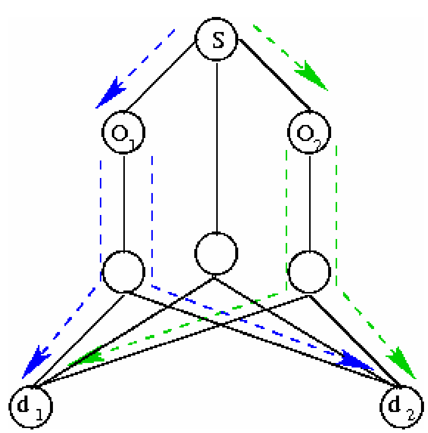
- Solutions for different network models
  - Traditional IP Networks
  - IP Networks with IP multicast capabilities (e.g. DVMRP).
  - Additional functionalities – smart routers
- Main features:
  - Measurement based solution - relies only on noisy cost estimates
    - Simultaneous Perturbation Stochastic Approximation (SPSA)
  - Weaker assumptions on cost function
    - Convex and continuous, <u>not</u> necessarily differentiable
  - Distributed implementation
    - Theoretical convergence to a global optimum

Existing Work

- Multi-tree Routing:
  - K. Park and Y. Shin
    - "Uncapacitated point-to-multipoint network flow problem.", European Journal of Research, 2003
  - Limited to single multicast source case
  - Assumes the existence of analytic cost gradients
  - Cost function is <u>strictly</u> convex, continuous and <u>differentiable</u>
- Network Coding:
  - Relies on the unrealistic assumption:
    - Network is lossless if link rates do not exceed the link capacity.
      - solutions work at rates that are prone to packet losses.
  - A single packet loss costly
    - Receiver requires the lost packet to decode a large block of data
  - High level of coordination and synchronism required
    - Frequent updates necessary every time a flow arrives/departs

Creating Multiple multicast paths

- Application Layer Overlays
  - Limited number of simple devices located inside the network
    - e.g. Network processors
  - Alternative paths created between a source and a destination
    - Min-hop path from source to overlay and from overlay to destination
  - Not necessarily creates multi-trees
  - Problem with multiple paths in multicast:
    - How to map packets to different paths for each destination to minimize the total number of packets sent at the source?
    - Complex bookkeeping problem
  - Soln: Digital Fountain Coding



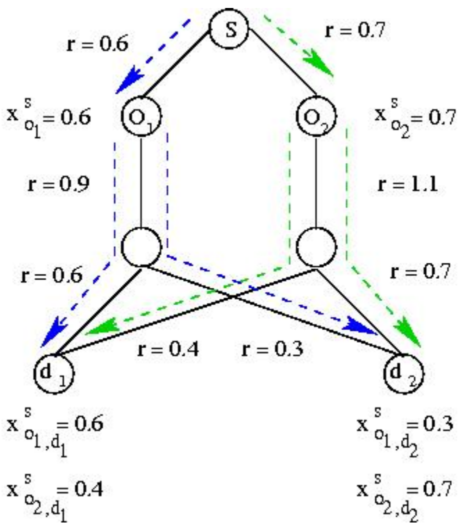
Digital Fountain Coding

- A special form of block coding with following properties:
  - Rateless coding
    - Number of encoded packets that can be generated from the source message is potentially limitless; can be determined on the fly
  - Each output symbol generated by the addition of randomly selected input symbols
  - Decoder can recover original K input symbols from any M output symbols with a high probability
    - e.g. Raptor Codes: for K = 64536 and M = 65552, error probability is 1.71×10^{-14}
  - Encoding and decoding complexity linear in K
  - Successful commercial implementation at several gigabits/sec by Digital Fountain Company
- Useful for multi-path multicast routing
  - Solves the bookkeeping problem
  - Routing algorithms merely needs to calculate the optimal path rates

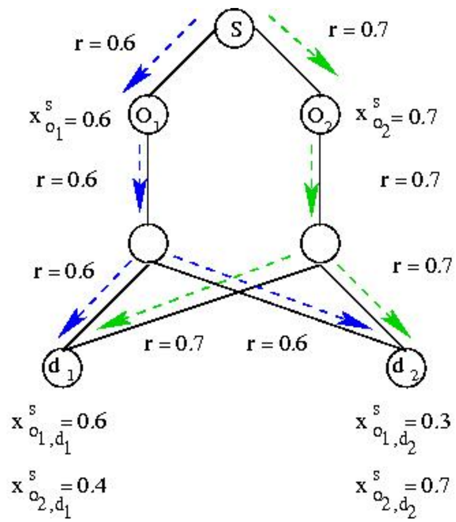
Network Models

- Network Model 1:
  - Traditional IP networks without any multicasting capability
- Network Model 2:
  - IP Multicast – e.g. DVMRP capable
- Network Model 3:
  - Smart routers

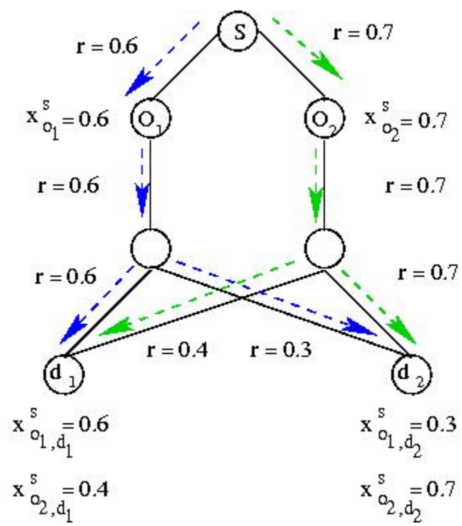
Nt Model 1



Nt Model2



Nt Model 3



Measurement-based multi-path multicast routing algorithms

- Stochastic Approximation
  - Useful tool for finding extrema of functions
  - Simultaneous Perturbation Stochastic Approximation:

$$x(k+1) = [x(k) - a_k \hat{g}(x(k))]^+$$

$$\hat{g}_i(x(k)) = \frac{y(x(k)+c_k\Delta_k) - y(x(k)-c_k\Delta_k)}{2c_k\Delta_{ki}}$$

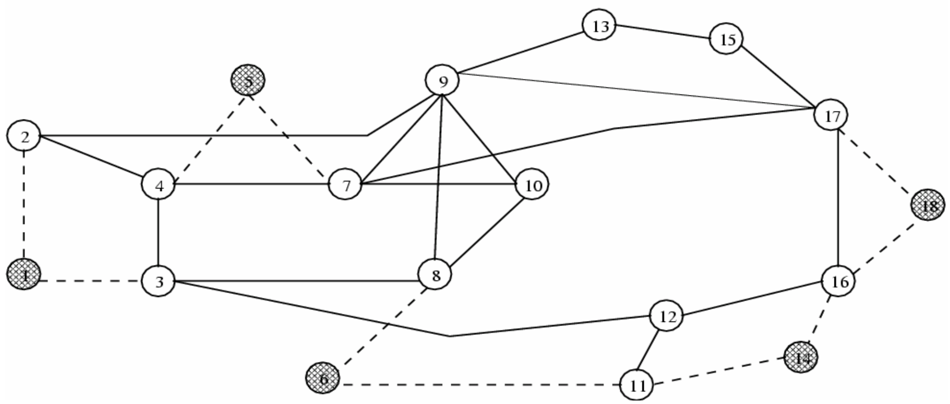
  - $x(k)$: input vector to be optimized
  - All elements of $x(k)$ *randomly* perturbed *together* to obtain two measurements $y(.)$
  - Δ_k the random perturbation vector with a specific random distribution satisfying necessary conditions.
  - $c_k > 0, a_k > 0.$

Benefits of SPSA-Based Optimal Routing

- Merits of the optimal routing algorithm
  - Distributed
  - Depends on local state information
  - Only noisy measurement required
  - Cost function assumed to be convex, continuous but not necessarily differentiable
- Can run the same algorithm under each network model
  - Analyze benefits of additional multicasting functionality

Simulation Results – (1)

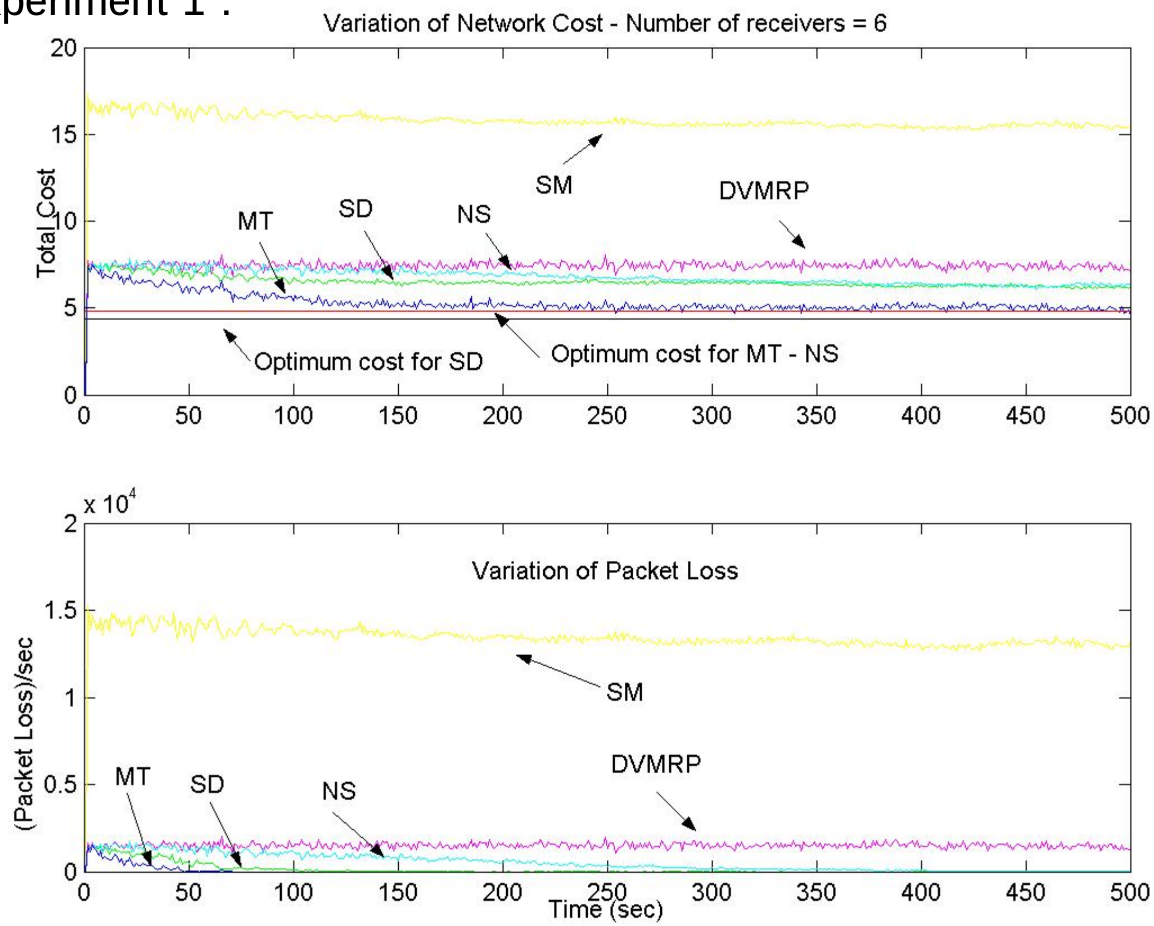
- Experiments
  - UUNet backbone topology



  - Link bandwidth: 20 Mbps
  - Nodes 1 and 5 are multicast sources
  - Each source creates 11.5 Mbps Poisson traffic
  - Nodes 9 and 17 are overlay nodes
    - each destination has 3 alternative paths

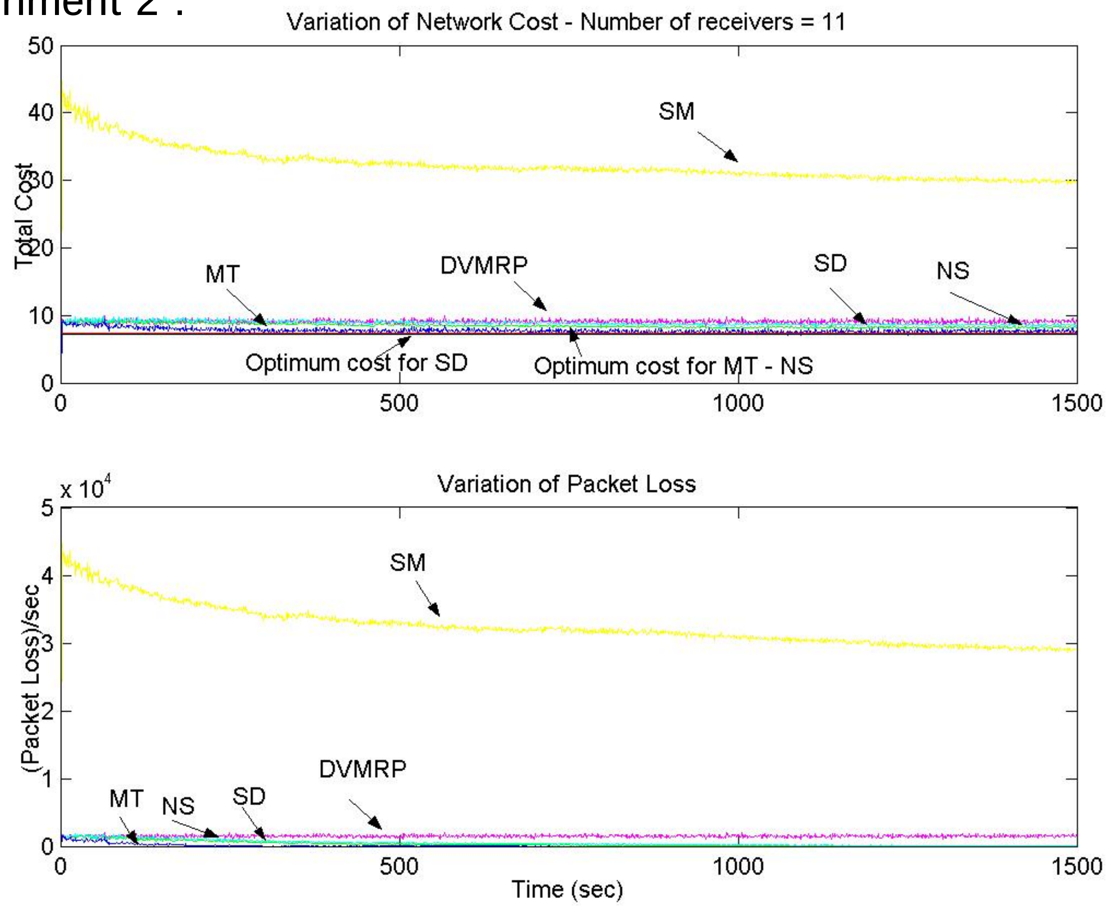
Simulation Results – (1) cont'd

- Experiment 1 :



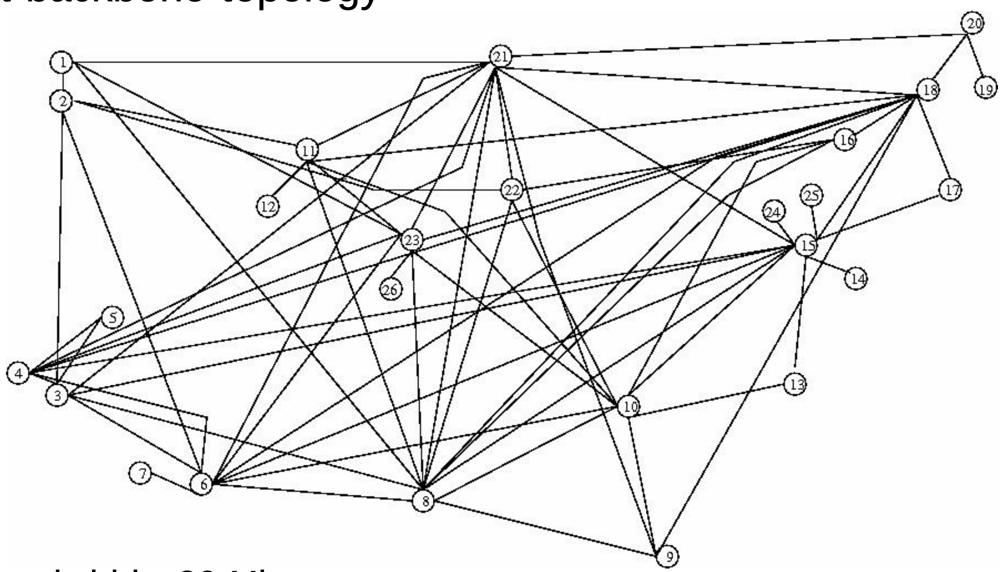
Simulation Results – (1) cont'd

- Experiment 2 :



Simulation Results – (2)

- Experiments
  - Sprint backbone topology



  - Link bandwidth: 20 Mbps
  - Nodes 1, 9 and 22 are multicast sources
  - Each source creates 10 Mbps Poisson traffic
  - Nodes 10 and 23 are overlay nodes. Hence each destination has 3 alternative paths
  - Each source has 18 receivers

Simulation Results – (2) cont'd