Developing the Science of Networks

# Benefits from Incremental Deployment of Inter-domain Routing Protocols

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## Introduction

- We consider a network of nodes that construct paths via a routing protocol, e.g. BGP
- Routing through a node is characterized by a metric, e.g. latency or throughput
- Some nodes can adopt a new, incrementally deployable routing protocol

*How does end-to-end routing performance change with incremental deployment of the new protocol?*

## Problem formulation

- We model a protocol via the amount and relevance of routing-metric information it provides to individual nodes
- Incumbent protocol:
  - Every node knows imprecisely the distributions of metric values for the other nodes
- New protocol:
  - Each of the adopting nodes almost surely knows the distributions of their metric values

## Mathematical description

- Building on [1, 4], we formulate traffic routing as an optimization problem :

$$min\ C(f) = \sum_{e \in E} l_e(f_e) f_e$$

$$s.t.\ f_e = \sum_{p\ such\ as\ e \in P} f_p\ \forall e \in E$$

$$\sum_{p \in P_i} f_p = d_i\ \forall i \in R$$

$$f_p \geq 0\ \forall p \in P$$

where *C(f)* – cost function, $f_p$ – flow through path *p*, $f_e$ - flow through edge *e*, $d_i$ – amount of traffic of flow *i*, $l_e$ - Lipschitz edge penalty function, E – set of edges, P – set of paths, R – set of flows

- A solution is a matrix representing distribution of flows across paths.

$$|S(X) - S(Y)| \leq L(\sum_{i=1}^{m} d_i |\beta(\sigma_i, \sigma_i)| + 2 * \sum_{i=1}^{m} d_i |\beta(\sigma_i, x_i)|)$$

where $\beta(x,y) = x^T(D^T D)y$ , $\sigma_i$ – column of the difference matrix

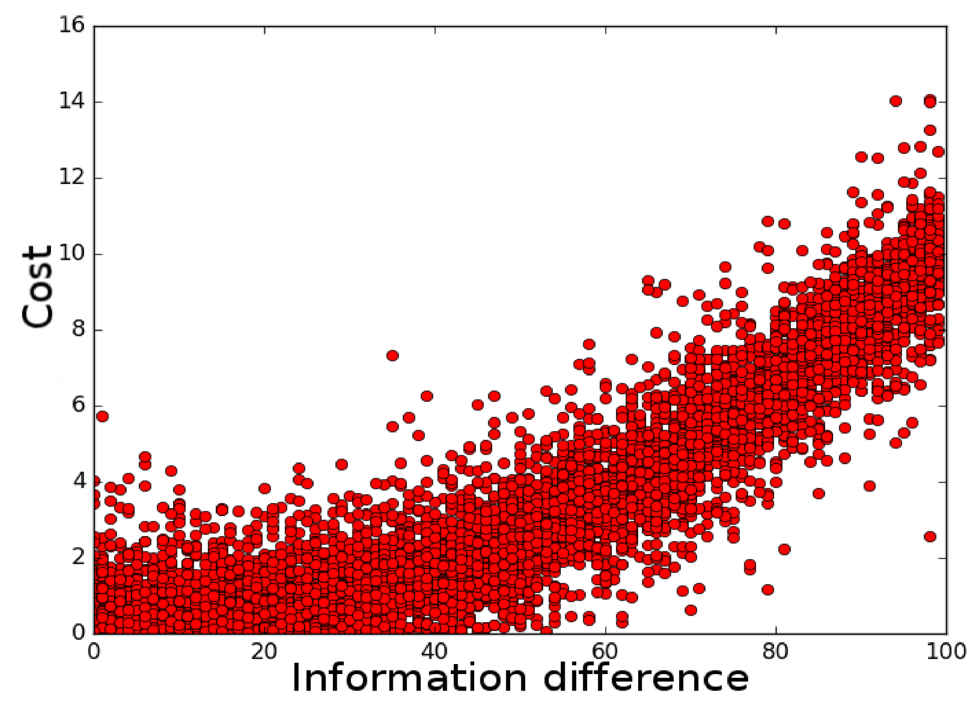
D – mapping paths to edges matrix, *L* – Lipschitz constant, m – number of flows

- Dependence of the cost difference on the solution difference is less than or equal to quadratic
- Small changes in the routing cause small changes in the cost function
- Significant changes of the cost function imply substantial changes in the routing

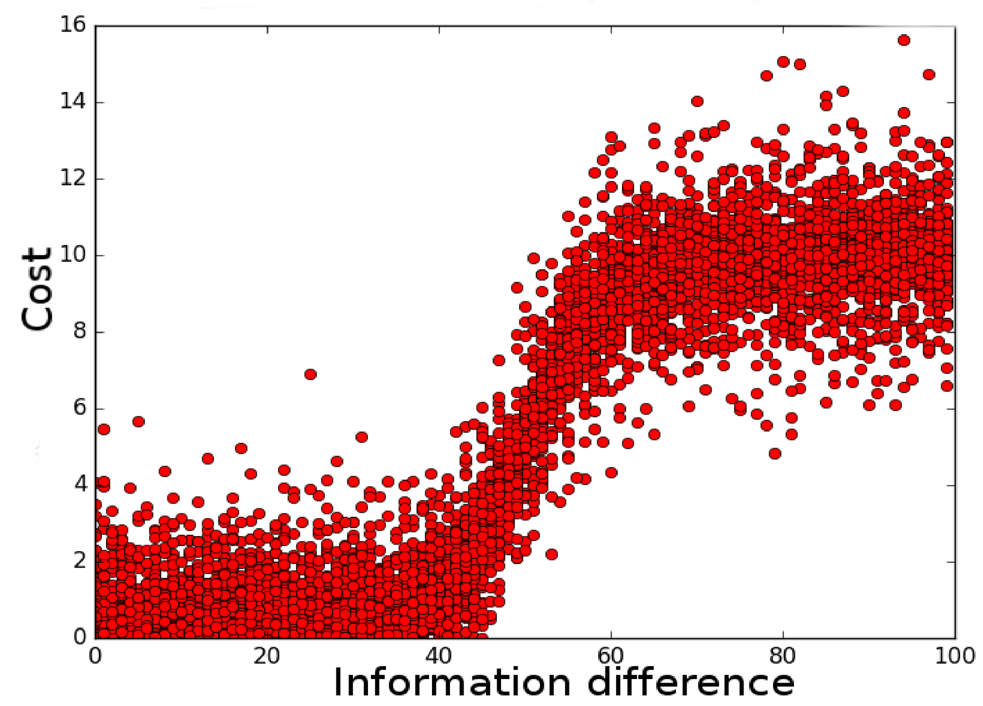
## Hypothesis

How do solutions depend on the available routing-metric information as the number of adopting nodes increasing?

- Smooth behavior



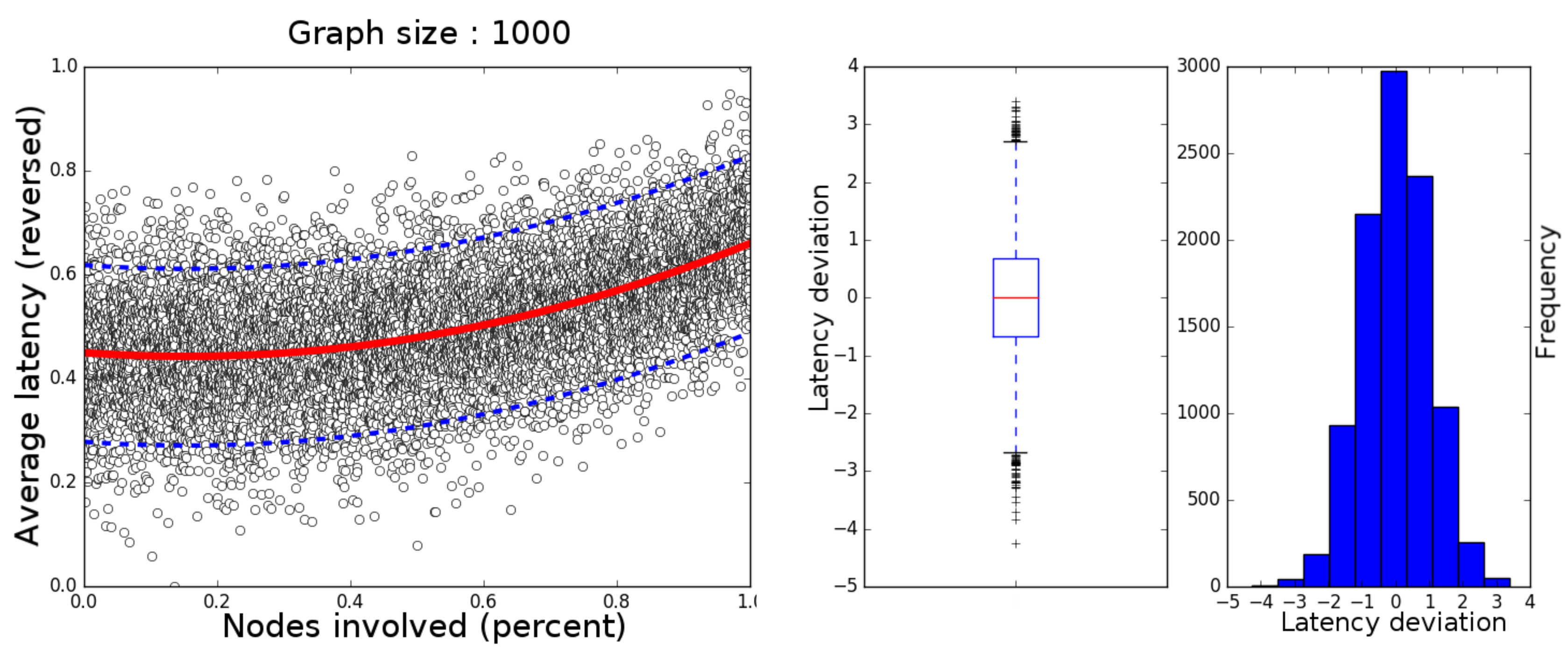

- Threshold behavior




## Evaluation

- We use our own discrete-time event simulator
- Nodes are Internet Autonomous Systems
- The topology is scale-free [2]
- Metric is latency
- Distributions of traffic and latency are based on real data [3]

## Results




- The improvement is smooth without a threshold
- Significant adoption is needed in order to yield a substantial fraction of the performance benefits

## Reference

[1] “How Bad Is Selfish Routing?” by Tim Roughgarden, Eva Tardos. Journal of the ACM, 2002

[2] “On Power-Law Relationships of the Internet Topology” by Michalis Faloutsos, Petros Faloutsos, Christos Faloutsos. ACM SIGCOMM 1999

[3] “An Empirical Evaluation of Internet Latency Expansion” by Hui Zhang, Ashish Goel, Ramesh Govindan. ASM SIGCOMM 2005

[4] “Selfish Routing in Capacitated Networks” by Jose R. Correa, Andreas S. Schulz, Nicolas E. Stier Moses. Mathematics of Operations Research 2004