Highly Optimized Tolerance (HOT) Model in Internet Topology Generator

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Outline

- Overview of topology generator.
- Highly Optimized Tolerance(HOT) Model.
- Our approach.
- Reference.

Need for Internet topology generator

- The scale of the Internet is immense.
- Security reason.
- Researchers use generated random network topologies instead.
- Applied areas:
  - Routing and multicast protocols
  - Traffic dynamics
  - Protocol behavior
- ns-2

Feature(s) of Internet topology

- …
- Power-law vertex degree distributions
  - Power-law are expressions of the form

    $y \propto x^{a}$, where a is a constant, x and y are the measures of interest, and $\propto$ stands for "proportional to".
- …

Physics Theories for the origin of Power-law

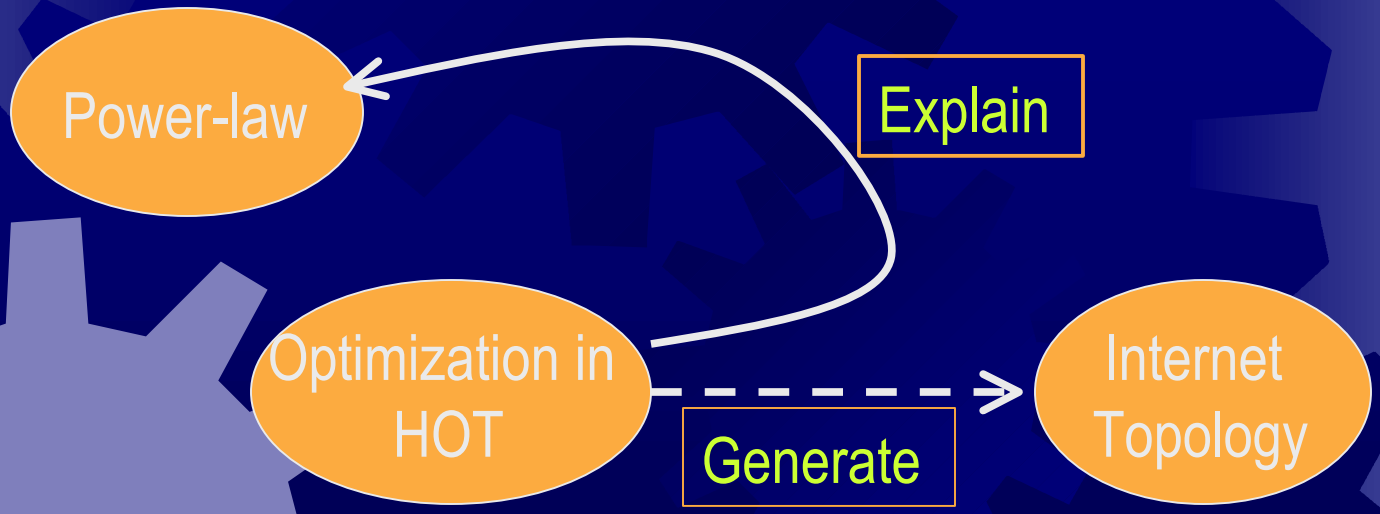
- Self Organized Criticality (SOC)
  - Waxman
  - Tiers
  - GT-ITM
  - BRITE
  - Inet
- Highly Optimized Tolerance (HOT)
  - ∅

Characteristics of HOT

- HOT system:
  - Efficient, high performance, and robust
  - Hypersensitive to design flaws and unanticipated perturbations
  - Nongeneric, specialized, structured configuration
  - Power law
- These features arise as a consequence of optimizing a “design” objective in the presence of uncertainty and specified constrains.

Our approach

- Generate Internet topology in the process of optimization Web layout design which explains the origin of heavy tails in Web traffic.



Our approach (Cont'd)

- Internet is a HOT-related system.
- Heavy tails appear in network traffic is related to power-laws.
  - A variable X follows a heavy tail distribution with $P[X>x]=k^{a} x^{-a} L(x)$, where $k \in \Re^{+}$ and $L(x)$ is a slowly varying function: $lim_{t \to \infty}[L(tx)/L(x)]=1$.

A simple example of HOT--PLR

- Probability-loss-resource(PLR) problem.
  - Loss: Cost associated with each event in a developing system.
  - Resource: Elements to limit loss.
  - Probability: Event probability.

A simple example of HOT--PLR (Cont'd)

- Objective: To minimize cost by optimization the "design" objective.
- Key function $l_i = f(r_i)$ s.t. resource(r_i) acts to limit the cost of events(l_i). And $l_i \propto r_i^{-\beta}$.
- Functional result: $p_i = c_1(l_i + c_2)^{-(1+1/\beta)}$

(p_i=noncumulative probability distribution, c_1, c_2=free parameters)

Introduction of our approach

- Consider a Web site modeled as a directed graph(V, E), where:
  - Node V_i(I=1…N) represents a Web page.
  - Directed edge E_{ij} represents a hyperlink pointing from page V_i to page V_j.
- The goal is to minimize the download time user experiences when accessing each Web page.

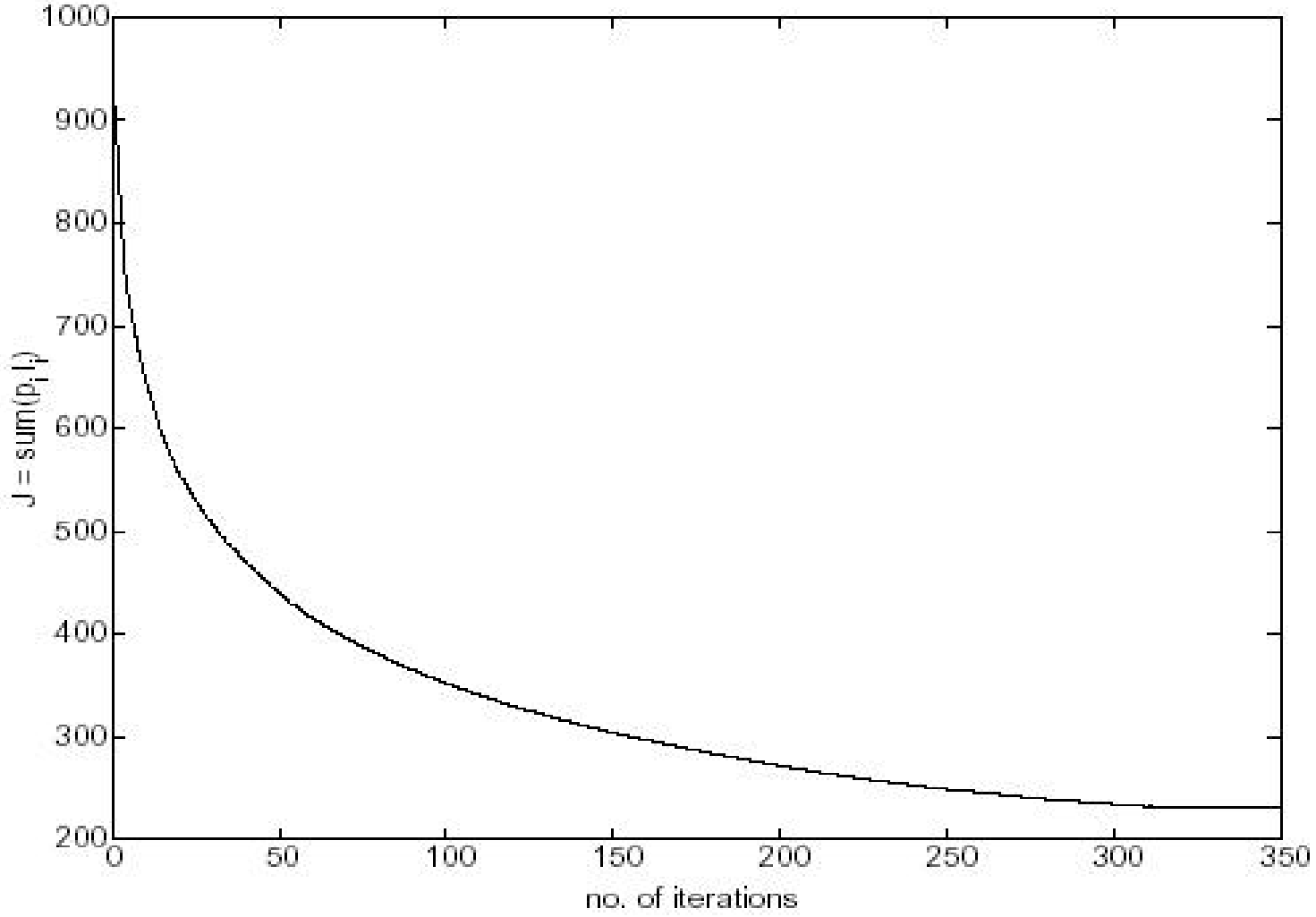
Introduction (Cont'd)

- Associate "design" with subdivision of large documents into files.
- The size of events (l_i) are file lengths.
- Noncumulative probability distribution (p_i) are determined by user navigation pattern in the file.
- The cost $J=\sum p_i l_i$ is the average delay a user experiences in downloading files.
- The resources r_i divide the document into files,where large r_i correspond to small files and vice verse.

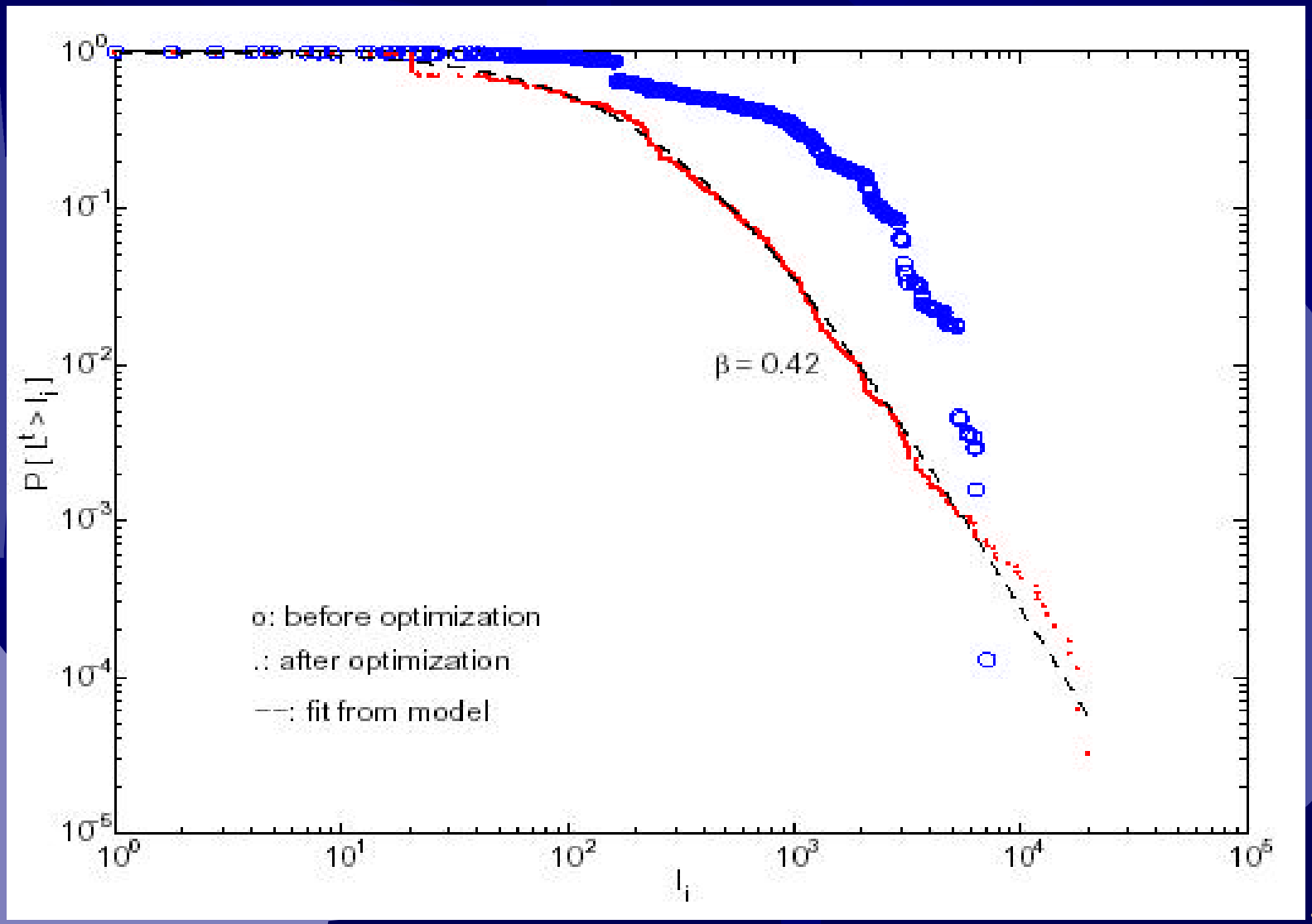
Details

- Initialization of the Graph Model
  - Wax man's network model as the initial topology graph.
  - Markov chain as the user navigation pattern.
  - Exponential distributions for file sizes l_i
- Heuristic Optimization
  - Splitting: split vertex with the highest $p_i l_i$.
  - Merging: merge 2 vertices after 1 splitting.
  - Iteration: stop till the improvement of J is within a certain tolerance level or the # of iterations reaches a preset maximum.

Paper Result



Paper Result (Cont'd)



Paper Result (Cont'd)

- Hyperbolic function:

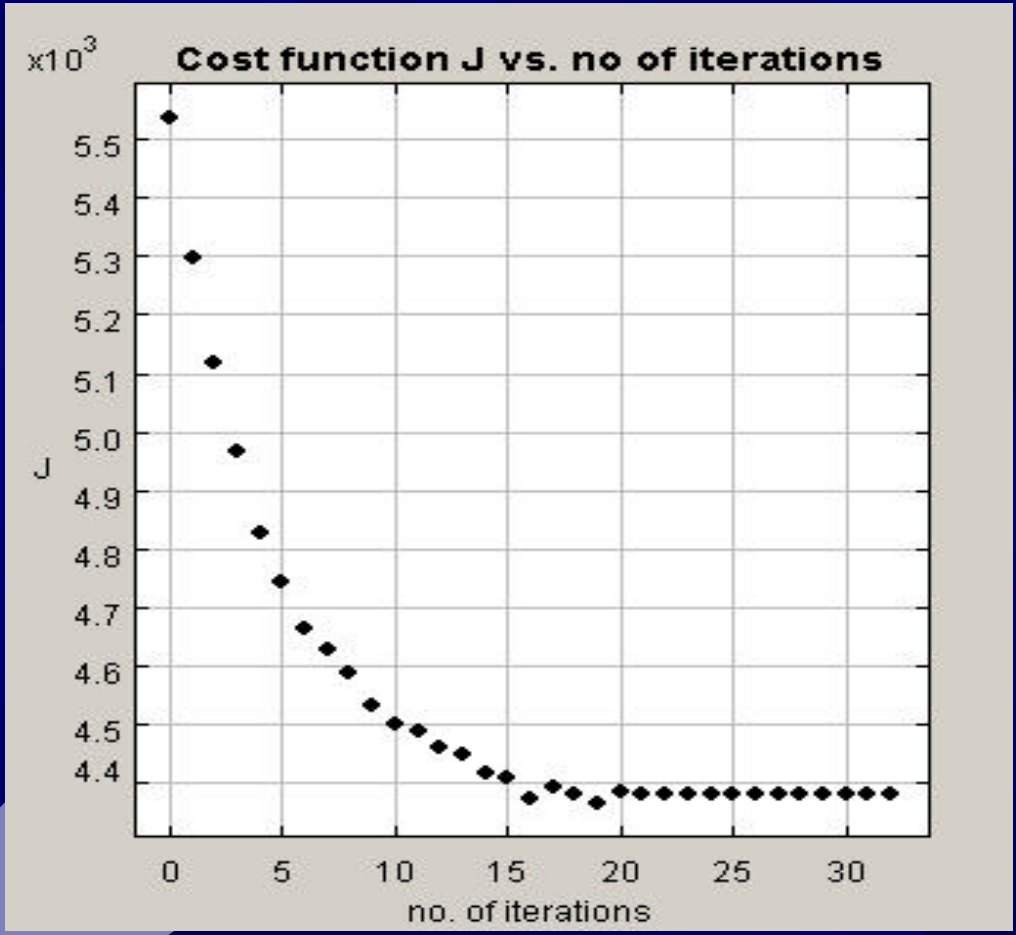
$$P_i = c_1(I_i+c_2)^{-1/\beta}$$

Cumulative probability $Pi=\sum_{j\le I} p_j$,

$c1=7.85*10^5$, $c2=318.28$, $\beta=0.42$

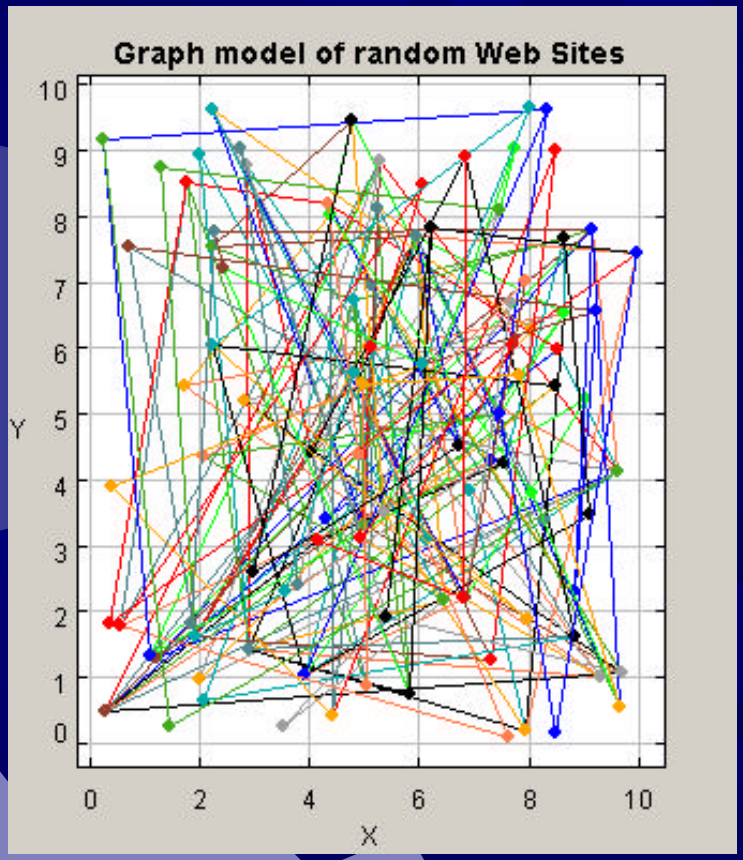
The required elements(nodes, links etc.) for a topology generator are computed during the process.

Our Result

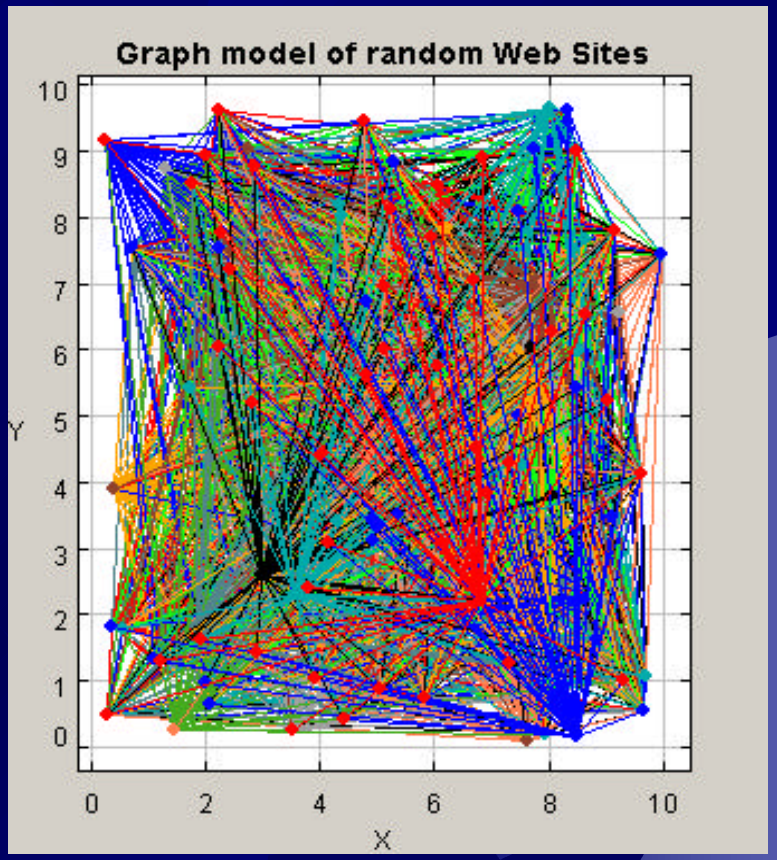


(100 nodes)

Our Result (Cont'd)

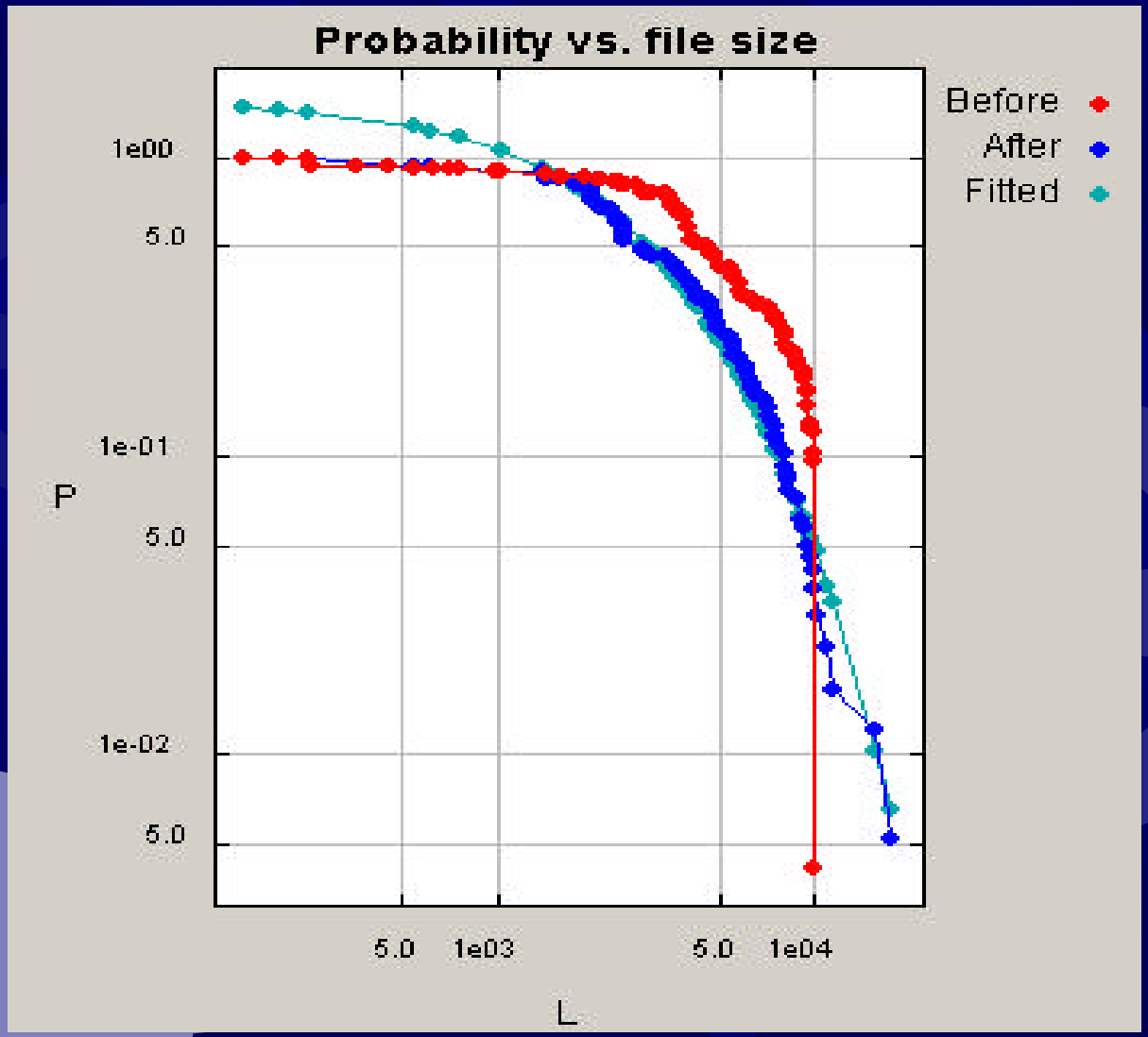


(Before Optimization)

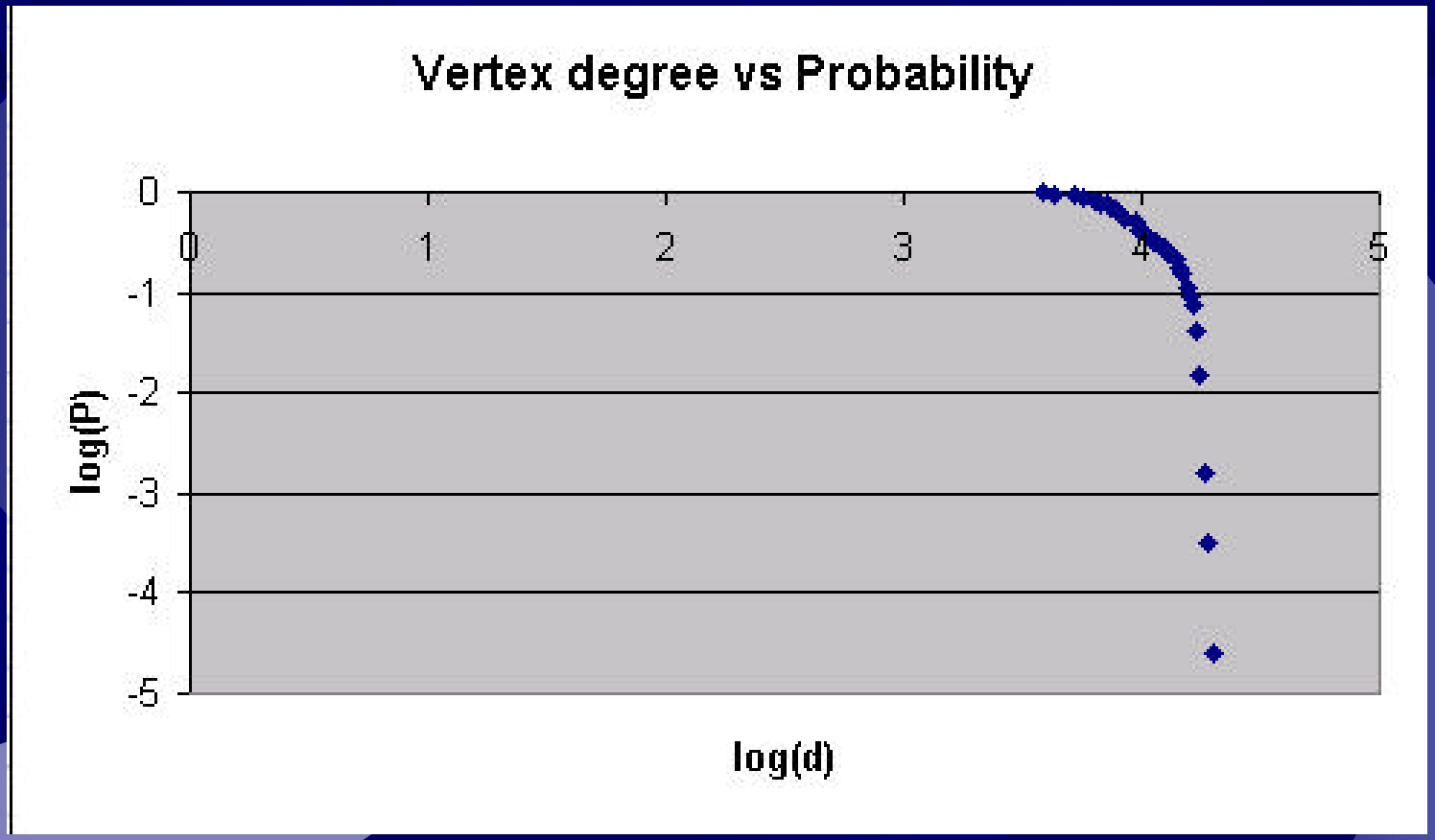


(After Optimization)

Our Result (Cont'd)



Our Result (Cont'd)



Conclusion

- We verified that HOT mechanism can generate Power-law distribution.
- HOT process can be used to generate Internet Topology.

Reference

- Qian Chen, et al. The Origin of Power Laws in Internet Topologies Revisited. (To appear)
- Carlson, J. and Doyle, J. (1999). Highly optimized tolerance:A mechanism for power laws in designed systems. Phys. Rev. E, 60:1412-1427.
- Doyle, J. and Carlson, J. (2000). Highly optimized tolerance and generalized source coding. Phys. Rev. Lett., 84(24):5656-5659.
- C.Faloutsos, P.Faloutsos, and M.Faloutsos,(1999). On Power-Law Relationships of the Internet Topology, in Proceedings of the ACM SIGCOMM.
- Xiaoyun Zhu, Jie Yu, and John Doyle. Heavy-Tailed Distributions, Generalized Source Coding and Optimal Web Layout Design. Technical Memorandum No. CIT CDS 00-001