

Ultra-Robustness and Scalability of Organizational Networks

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> Hewlett Foundation

> Office of Naval Research

Menu:

1. The basic idea/problem/motivation.
2. A model of organizational networks.
3. Message passing algorithm.
4. What we find.

February 1997:

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Recovered in 5 days.

February 1997:

- 36 suppliers, 150 subcontractors
- 50 supply lines
- sewing machine maker produced 40 valves a day

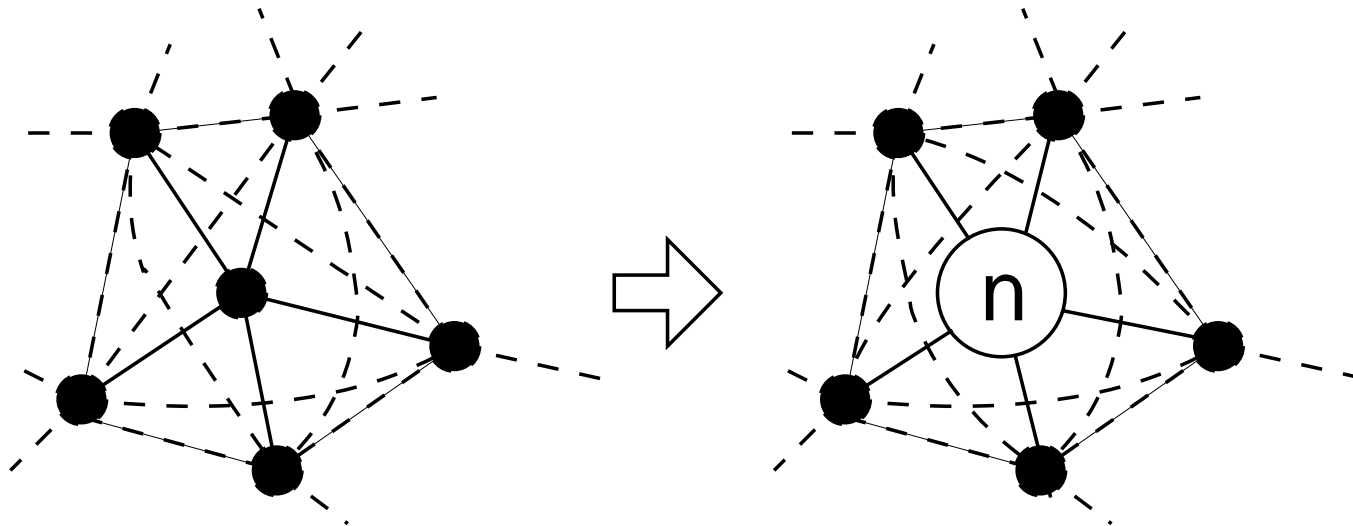
Recovery depended on horizontal links:

- robustness
- searchability

Why organizations exist:

Coase, 1937, "The Nature of the Firm"

- Transaction costs.
- More efficient for individuals to cooperate outside of the market.



Real organizations:

Extremes:

Hierarchy

- maximum efficiency
- suited to static environment
- brittle

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Hierarchy

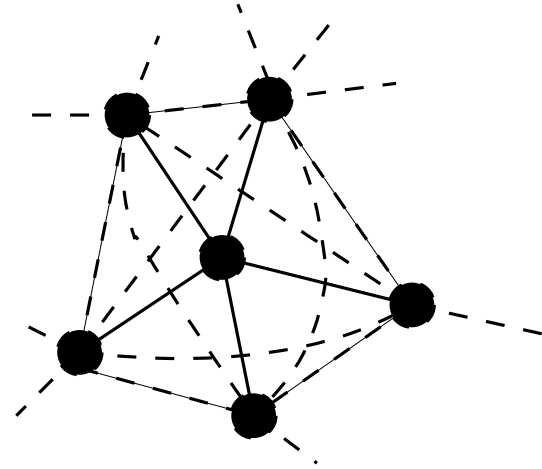
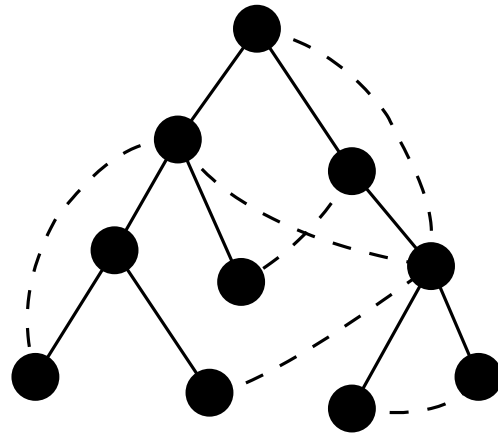
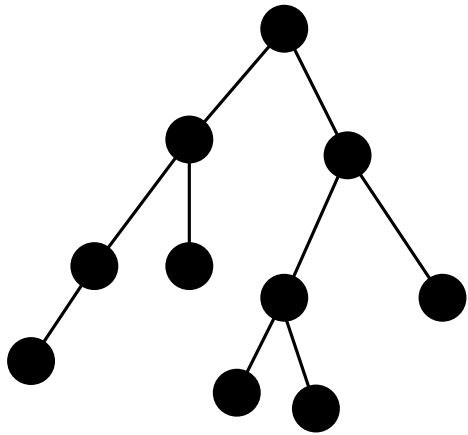
- maximum efficiency
- suited to static environment
- brittle

Market

- resilient
- suited to rapidly changing environment
- requires costless interactions

Real organizations:

But: Organizations are in the middle...



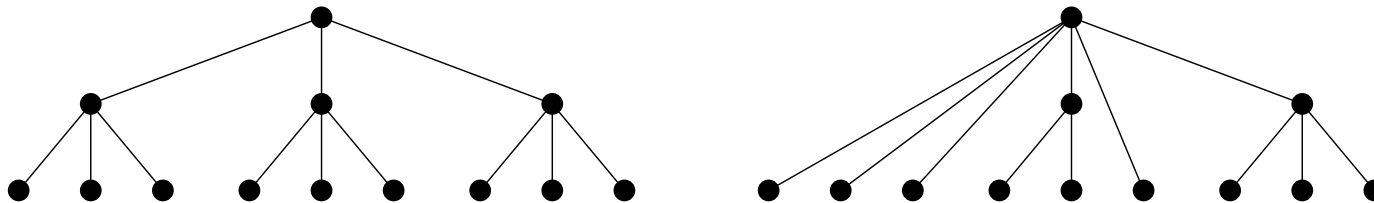
“Heterarchies” (D. Stark, 1999)

Organizations as efficient hierarchies:

Economics: Organizations \equiv Hierarchies.

e.g., Radner (1993), Van Zandt (1998)

Hierarchies performing associative operations:



Desirable organizational qualities:

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I. Congestion robustness

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I. Congestion robustness

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+

II. Connectivity robustness

(Recoverability in the event of failure)

Desirable organizational qualities:

2. Low cost (requiring few links)
3. Scalability
4. Ease of construction—existence is plausible
5. Searchability

Searchability:

Guimerà *et al.*, 2002

Optimal network topologies for searching using only local information.

Low cost searches \Rightarrow hub-based networks.

High cost searches \Rightarrow featureless networks.

Searchability:

Watts, Dodds, & Newman, 2002

Small world problem—can individuals pass a message to a target individual using only personal connections?

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Small world problem—can individuals pass a message to a target individual using only personal connections?

Yes, large scale networks searchable if nodes have **identities**.

Model:

Formal organizational structure:

- Underlying hierarchy

branching ratio b

depth L

$N = (b^L - 1)/(b - 1)$ nodes

$N - 1$ links

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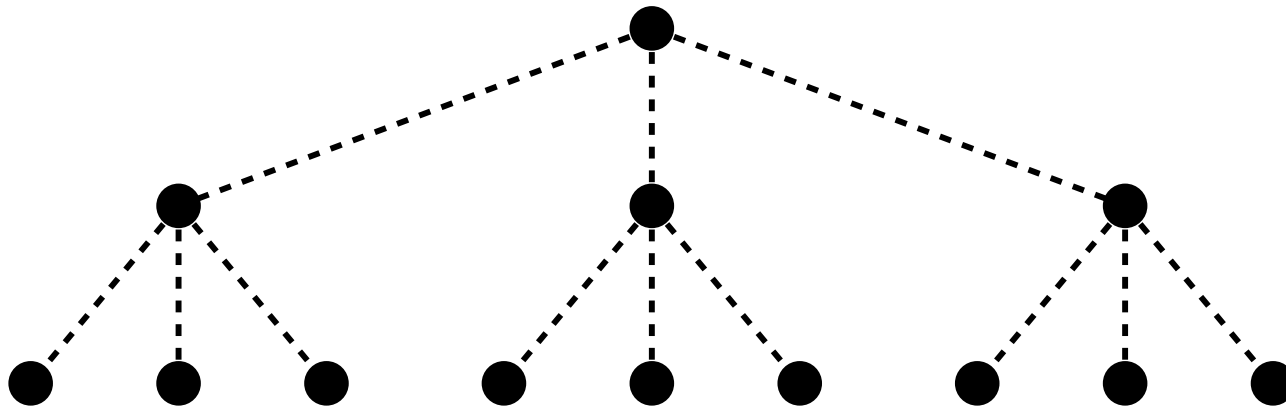
$N - 1$ links

Additional informal ties:

- Choose m links according to a two parameter probability distribution

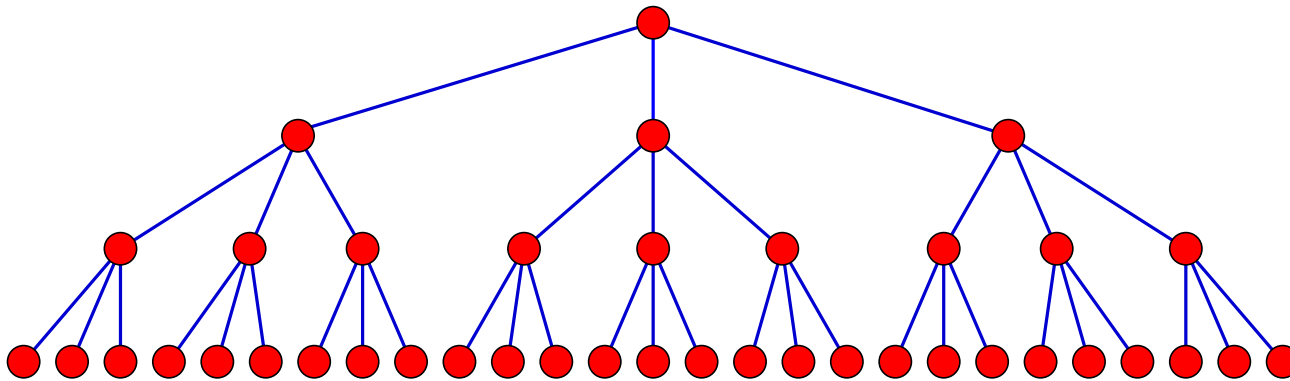
$$0 \leq m \leq (N - 1)(N - 2)/2$$

Model—underlying hierarchy:



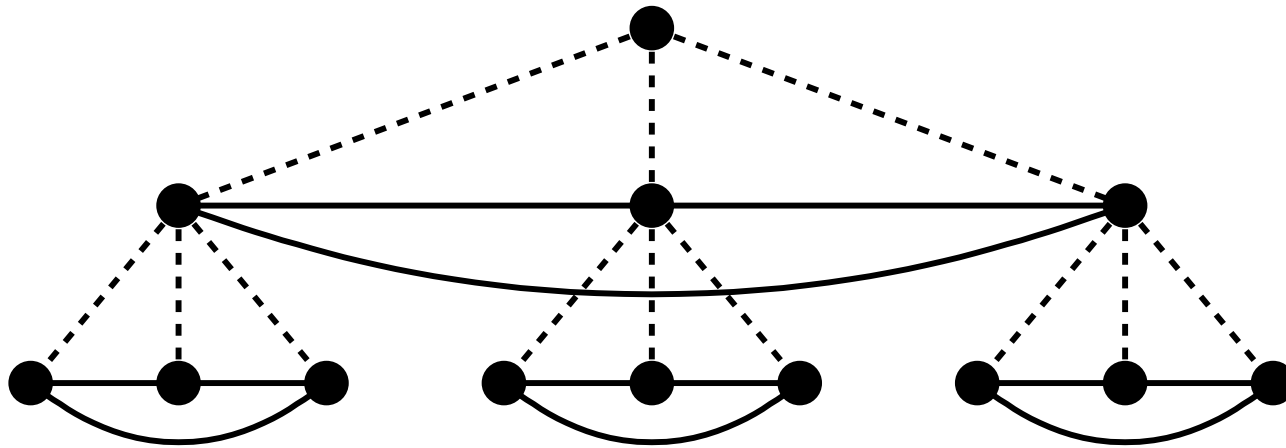
$$b = 3, \quad L = 3, \quad N = 13$$

Model—underlying hierarchy:



$$b = 3, \quad L = 4, \quad N = 40$$

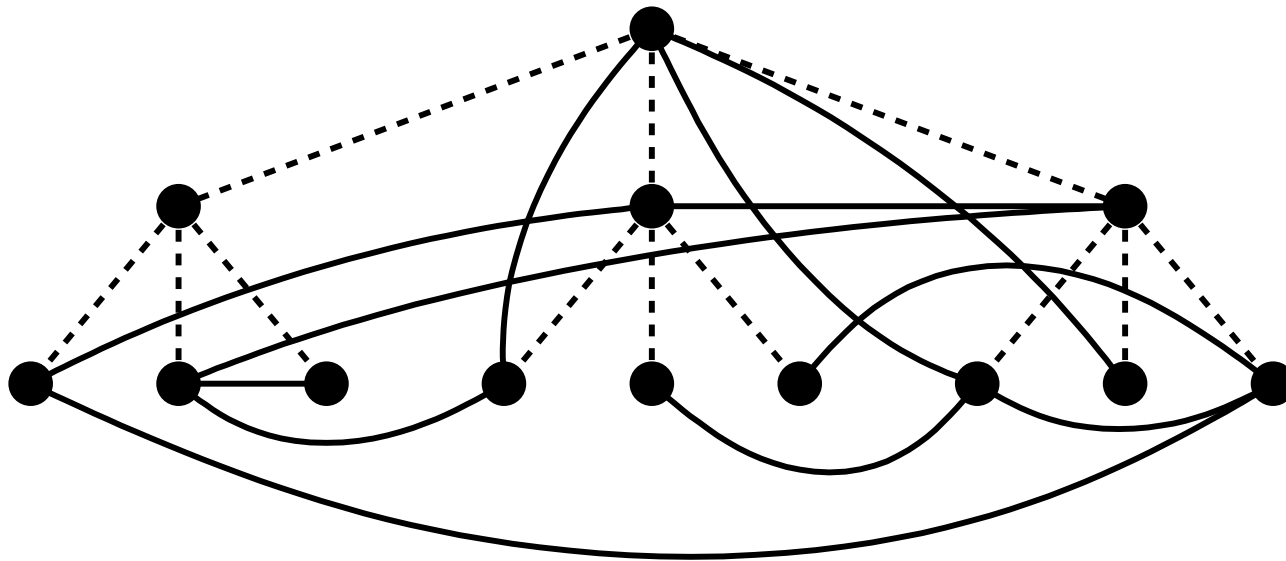
Model—addition of links:



Team-based networks

$m = 12$

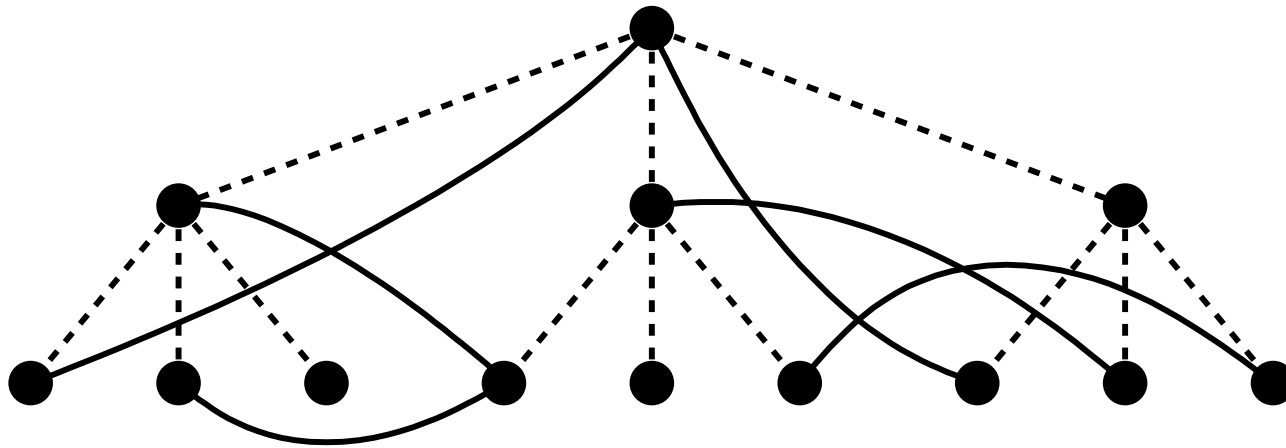
Model—addition of links:



Random networks

$m = 12$

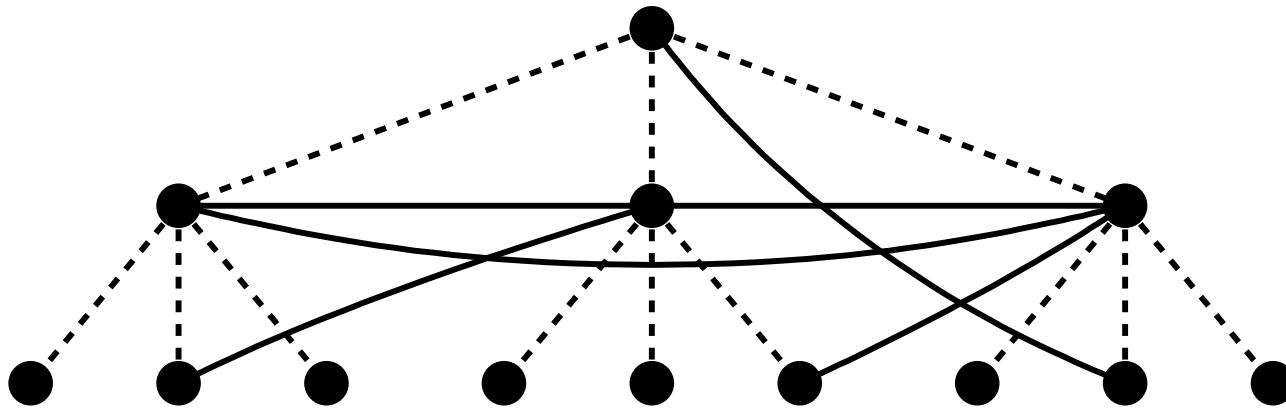
Model—addition of links:



Random interdivisional networks

$m = 6$

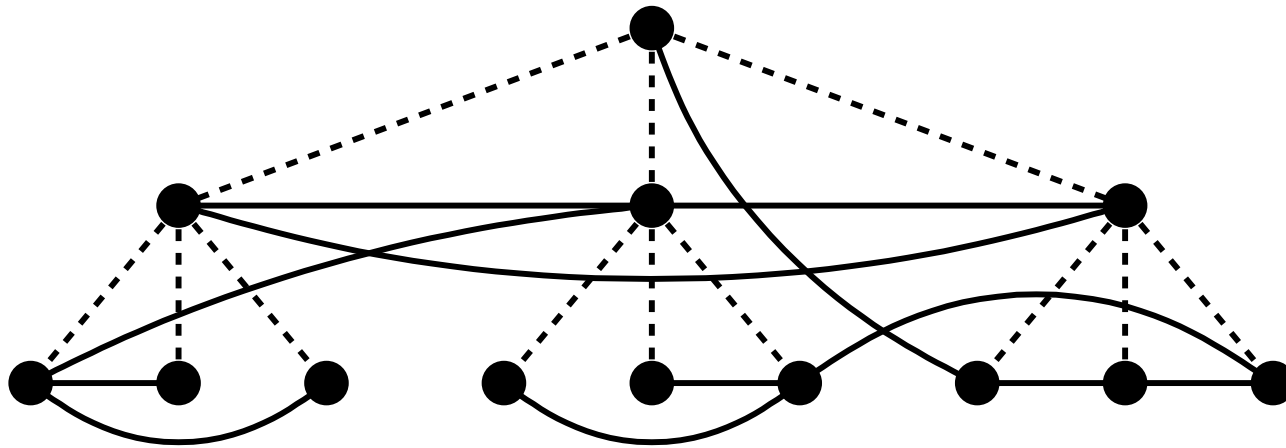
Model—addition of links:



Core-periphery networks

$m = 6$

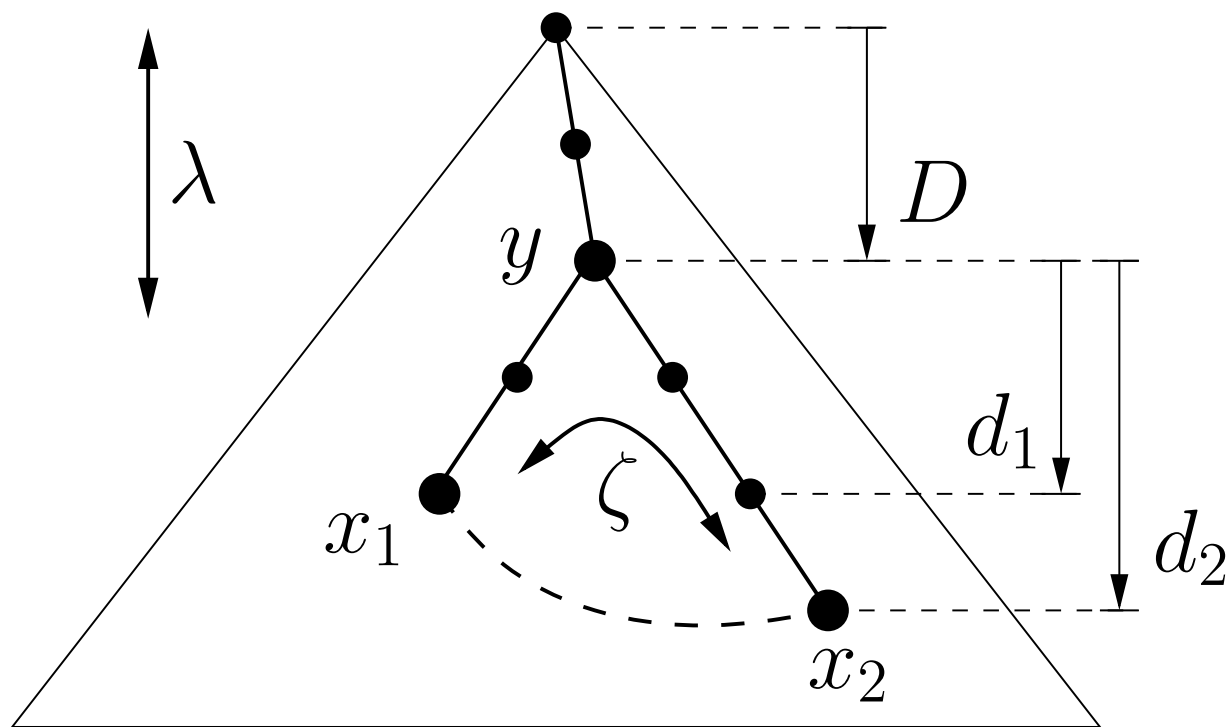
Model—addition of links:



Multiscale networks

$m = 12$

Model—construction:



Model—construction:

$$P(y, x_1, x_2) \propto e^{-D/\lambda} e^{-f(d_1, d_2)/\zeta}$$

- First choose (D, d_1, d_2) .
- Randomly choose (y, x_1, x_2) given (D, d_1, d_2) .
- Choose links without replacement.

Model—construction:

Requirements for $f(d_1, d_2)$:

1. $f \geq 0$ for $d_1 + d_2 \geq 2$
2. f increases monotonically with d_1, d_2 .
3. $f(d_1, d_2) = f(d_2, d_1)$.
4. f is maximized when $d_1 = d_2$.

Model—construction:

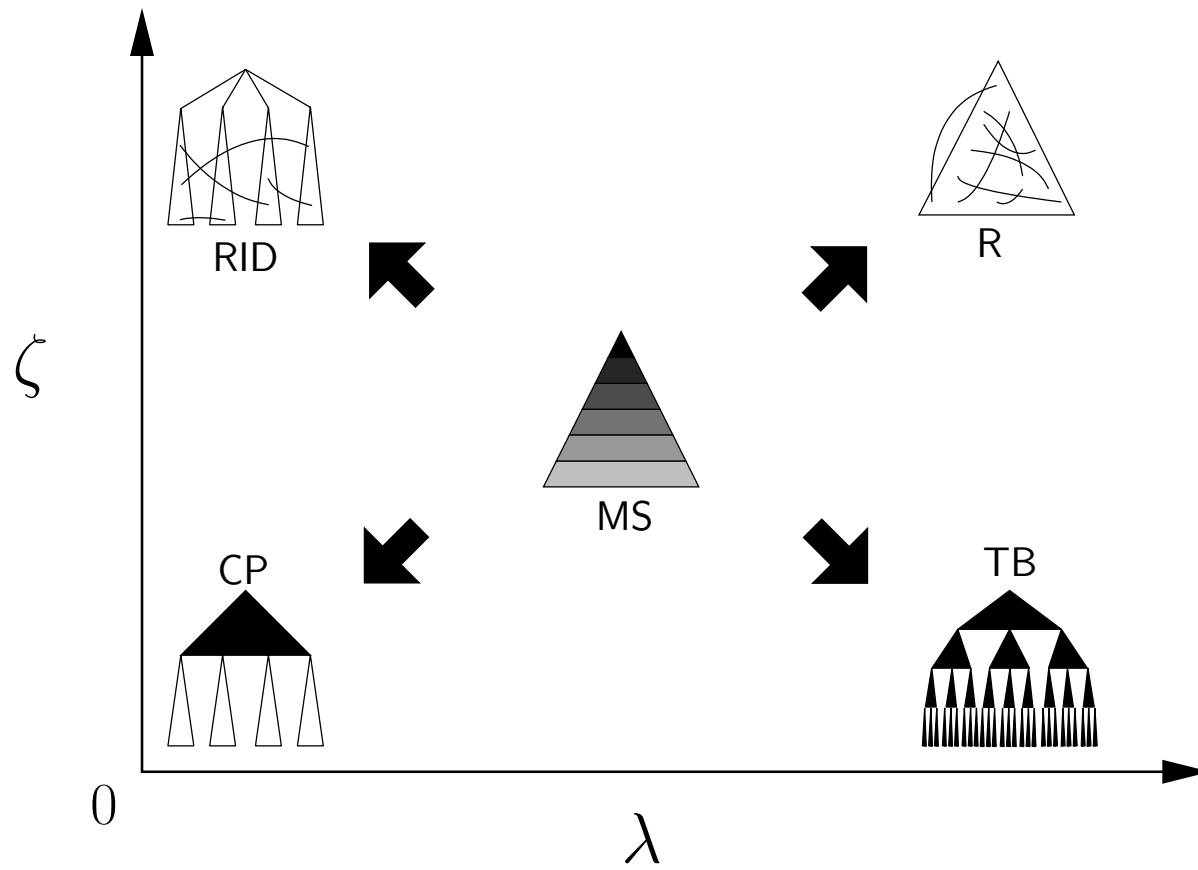
Simple function satisfying 1-4:

$$f(d_1, d_2) = (d_1^2 + d_2^2 - 2)^{1/2}$$

\Rightarrow

$$P(y, x_1, x_2) \propto e^{-D/\lambda} e^{-(d_1^2 + d_2^2 - 2)^{1/2}/\zeta}$$

Model—limiting cases:



Message passing pattern:

- Each of T time steps, each node generates a message with probability μ .
- Recipient of message chosen based on distance from sender.

$$P(\text{recipient at distance } d) \propto e^{-d/\xi}$$

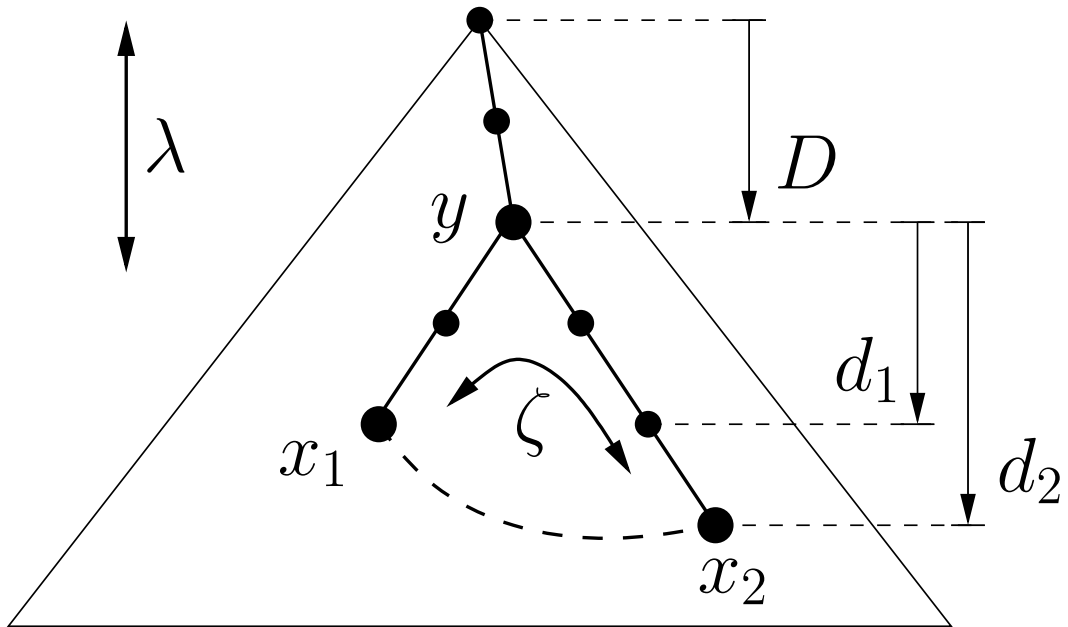
$\xi = 0$: local message passing

$\xi = \infty$: random message passing

Message passing pattern:

Distance d_{12} between two nodes x_1 and x_2 :

$$d_{12} = \max(d_1, d_2) = 3$$



Measure unchanged with presence of informal ties.

Message passing pattern:

Simple message routing algorithm:

Look ahead one step:

always choose neighbor closest to recipient node.

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Simple message routing algorithm:

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always choose neighbor closest to recipient node.

1. Nodes understand hierarchy.
2. Nodes know only local informal ties.

Message passing pattern:

Interpretations:

1. Sender knows specific recipient.

Message passing pattern:

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1. Sender knows specific recipient.
2. Sender requires certain kind of recipient.

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3. Sender seeks specific information but recipient unknown.

Message passing pattern:

Interpretations:

1. Sender knows specific recipient.
2. Sender requires certain kind of recipient.
3. Sender seeks specific information but recipient unknown.
4. Sender has a problem but information/recipient unknown.

Results:

Parameter settings (unless varying):

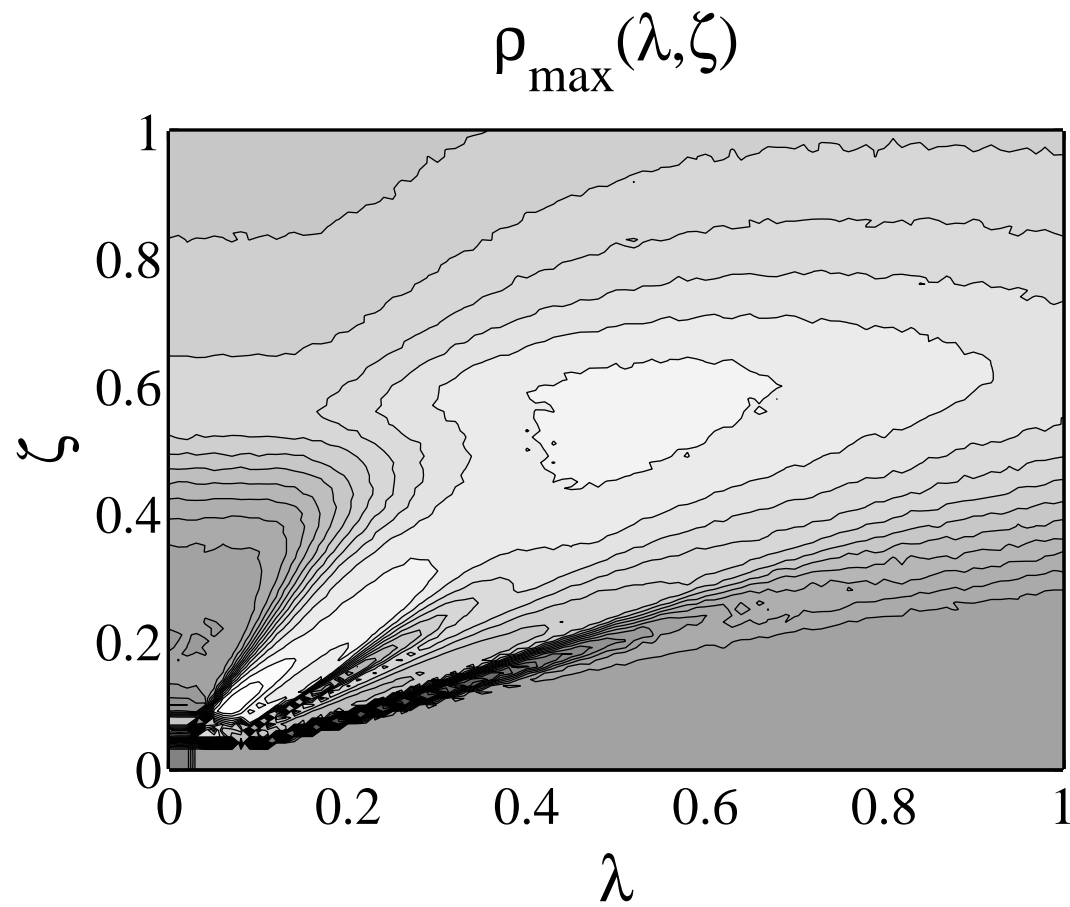
Underlying hierarchy: $b = 5$, $L = 6$, $N = 3096$

Number of informal ties: $m = N$

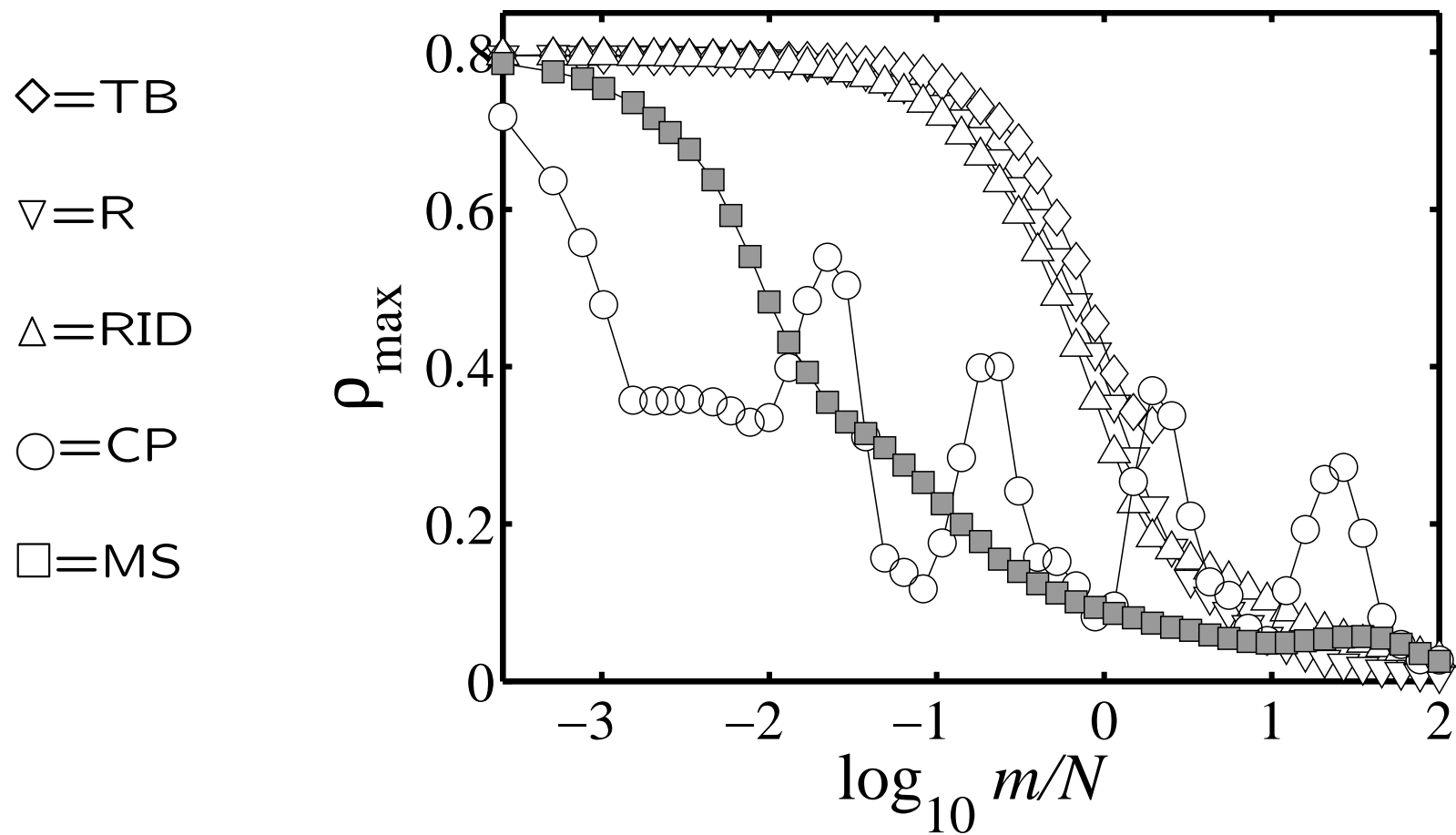
Link addition algorithm: $\lambda = \zeta = 0.5$

Message passing: $\xi = 1$, $\mu = 10/N$, $T = 1000$

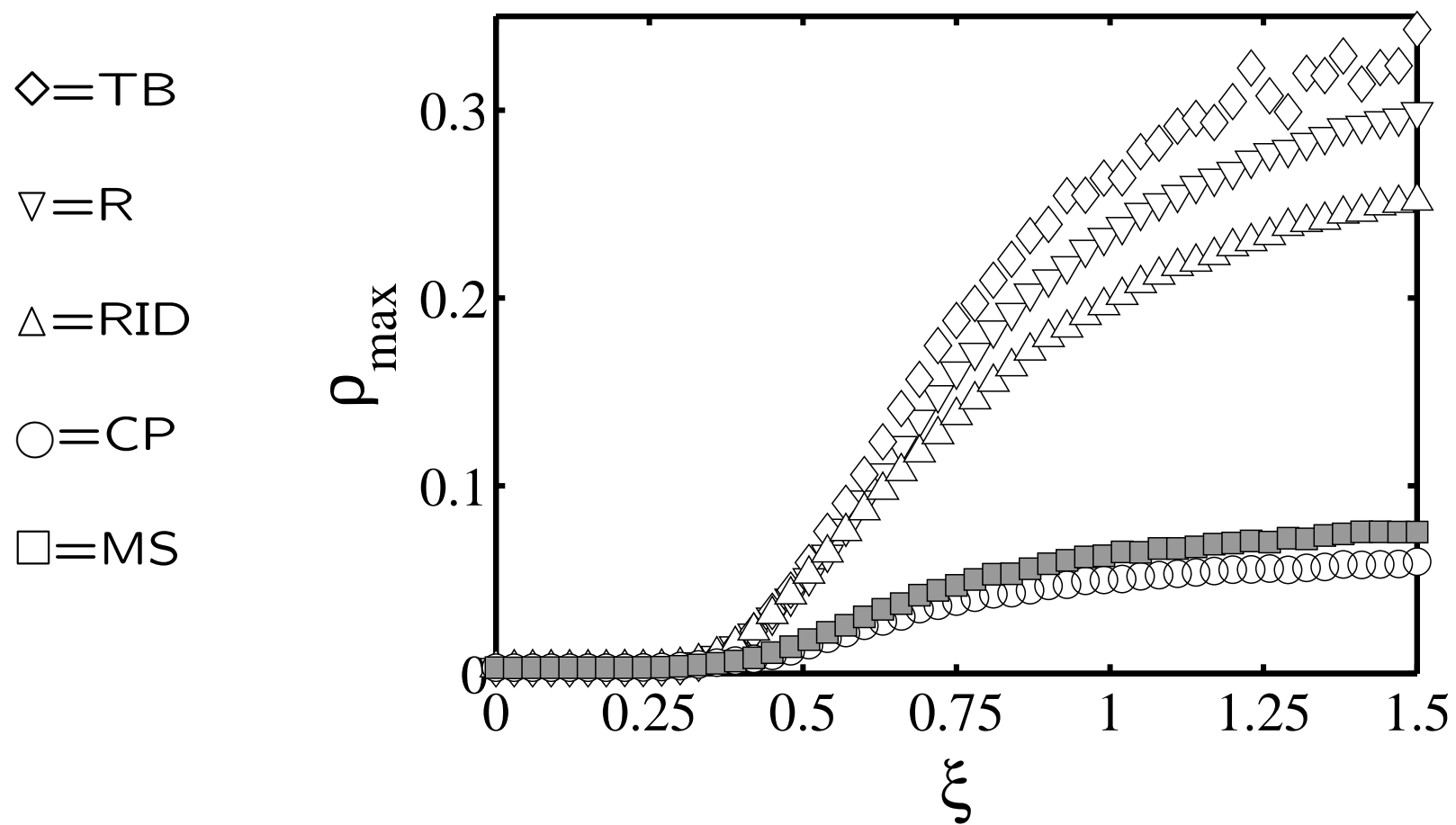
Results—congestion robustness:



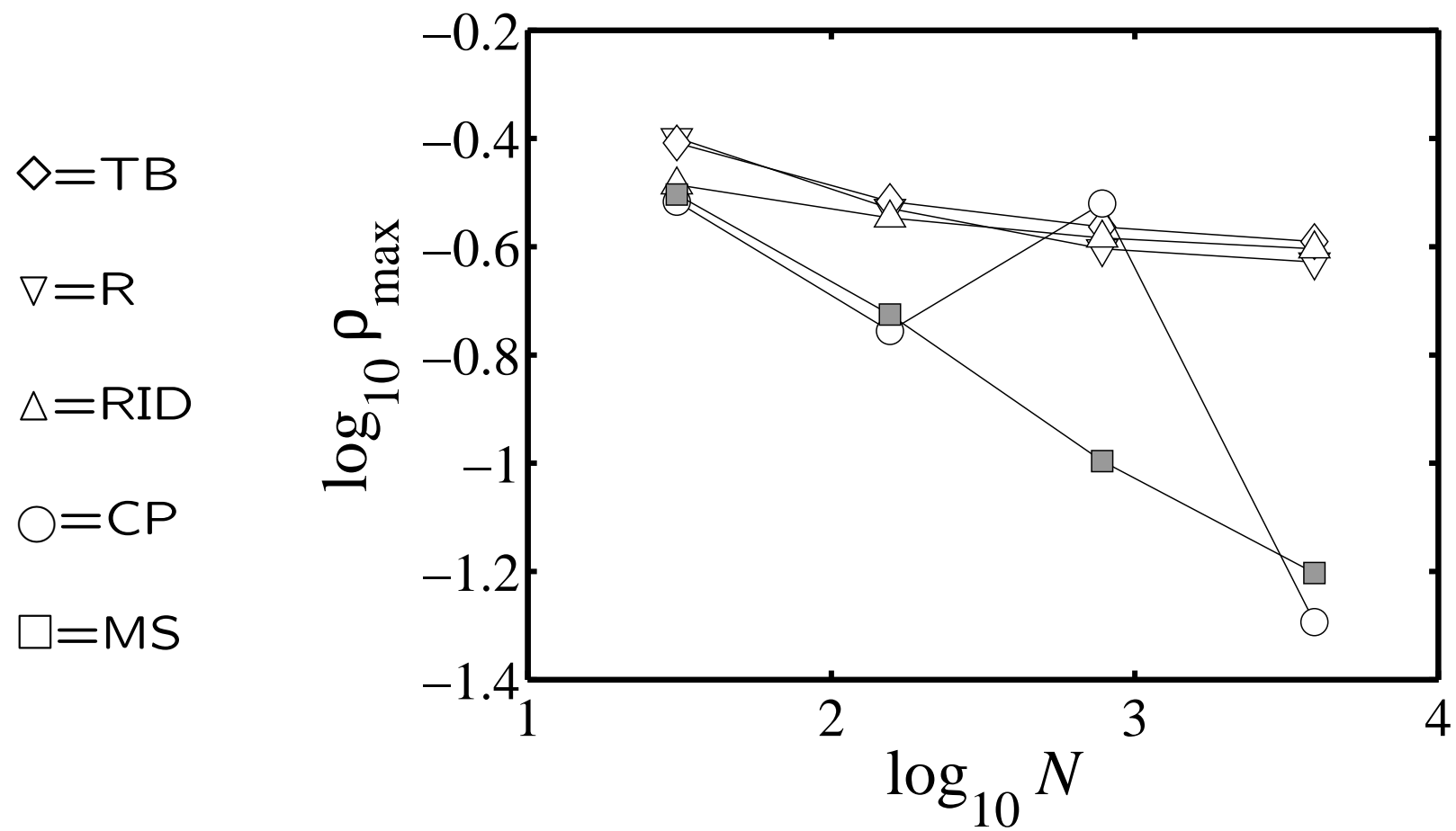
Results—varying number of links added:



Results—varying message passing pattern:



Results—Scalability:



Results—connectivity robustness:

