-Complex Networks 1.4-

A self-organized design of efficient and strong robust communication networks

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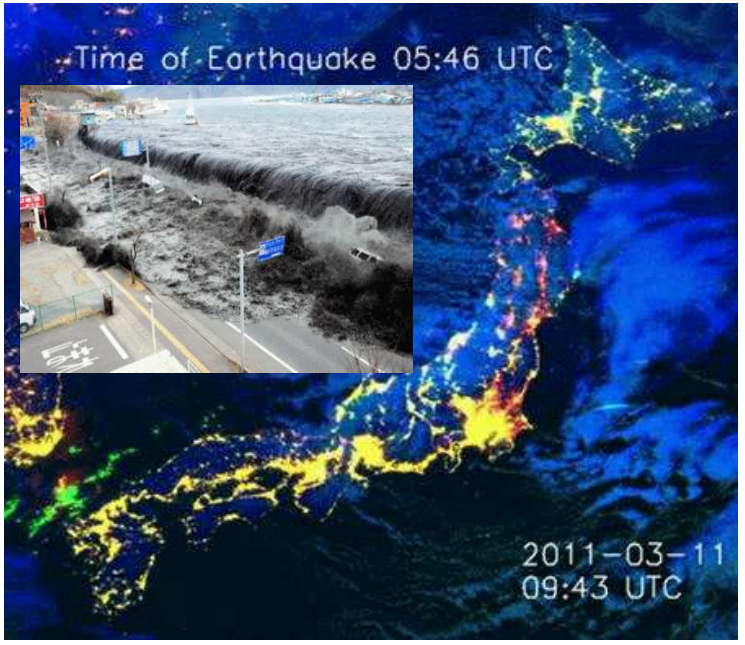
Unheared-of earthquake M9.0



What happened -other disorder

Further indirect damages

Caused by uncertain, incorrect, and insufficient information

- impossible distribution of drugs, cloths, foods, etc. from temporal storehouses to each evacuation area
- no-accepted miritary rescues as long as goverment requires (but already destoryed org.)
- stopping of distant industry supply-chains by lack of parts or the substitutes
- rumors for agricultural and marine products (e.g. radioactive contamination)
- ⋮

Lifelines interaction

Only experimental analysis of interaction between macroscopic industry domains, it's too rough sketch !

from \ to	water	gas	e-power	comm.	transport	waste
water	-	%	%	%	%	%
⋮		⋱				
comm.	%	%	%	-	%	%
⋮					⋱	
waste	%	%	%	%	%	-

Comm. are particularly important for the regulation and the control of other complex systems: railways, airlines, traffic, energy or food supply, economic, etc.

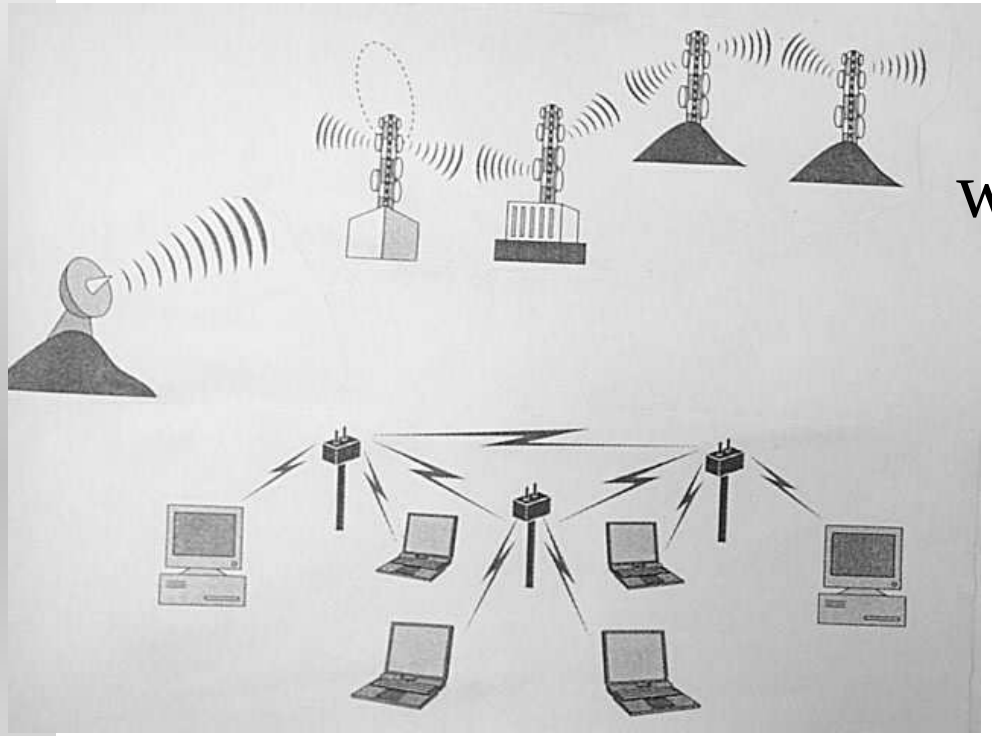
Current technologies

L:Portable satellite equipment R:Movable base-station

We have already some elemental technologies for emergent wireless communication

$\Rightarrow$ Cooperative supports by local communities are very important at social level

Extendable wireless comm.



with long-range [km] and directional [$\theta > 30°$] beams for wide-area wireless communication at physical device level

However, there are no systematic ways for network construction, proper setings of nodes (positions) and linkings are not designed !

Many real-nets are SF

Common networks structure: $P(k) \sim k^{-\gamma}$

Tech.: airline, Internet(AS, router), WWW, power-grid, P2P, electric circuit

Social: acquaintance relationship, actor collaboration, citation, sexual contact, e-mail, language

Bio.: neural network(C.elegance), gene network, matabolic pathway, food chain

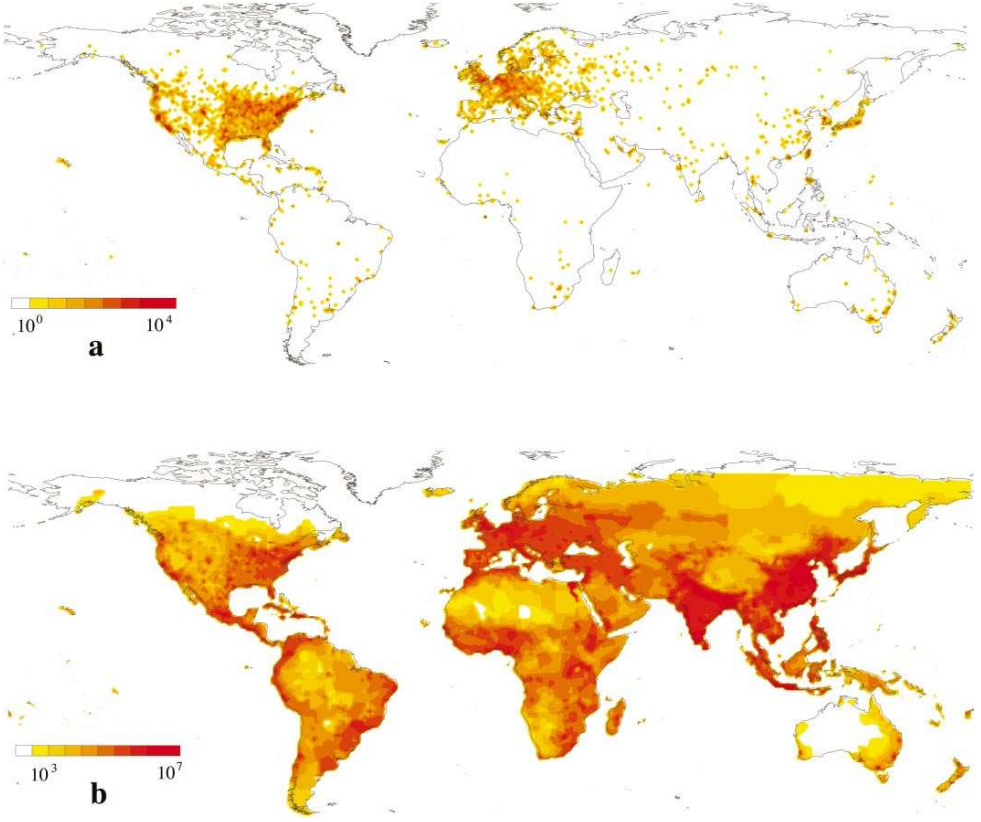
generated by the universal mechasism: rich gets richer
$\Rightarrow$ It is efficient with short paths but extremely vulnerable against hub attacks

A.L. Barabási et al., Physica A, 272, 1999

Necessary spatial structure

Nodes are emebedded on a space, whose potisions are neither unformly random nor on a regular lattice

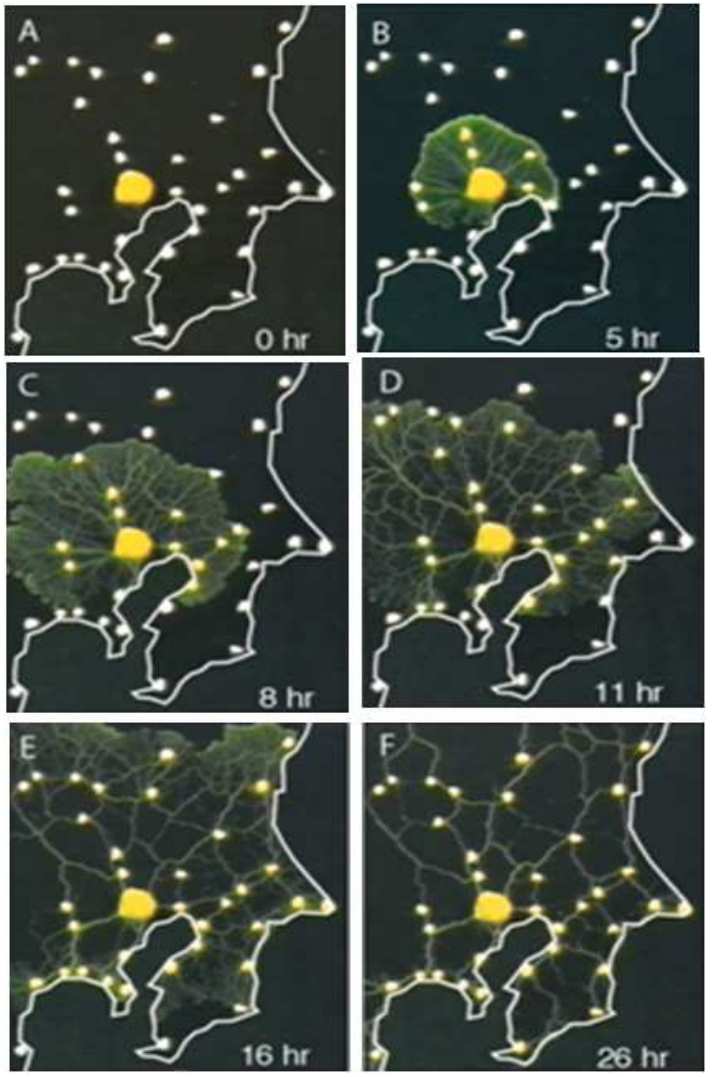
Density maps of router(top) and population(bottom)



Yook, Jeong, Barabási, PNAS 99(21), 2002

Remarkable 1

- Slime mold in growing to approach food sources
- Diffusive growth toward chemotxis in leaf venation and morphogenesis
- Human trail systems

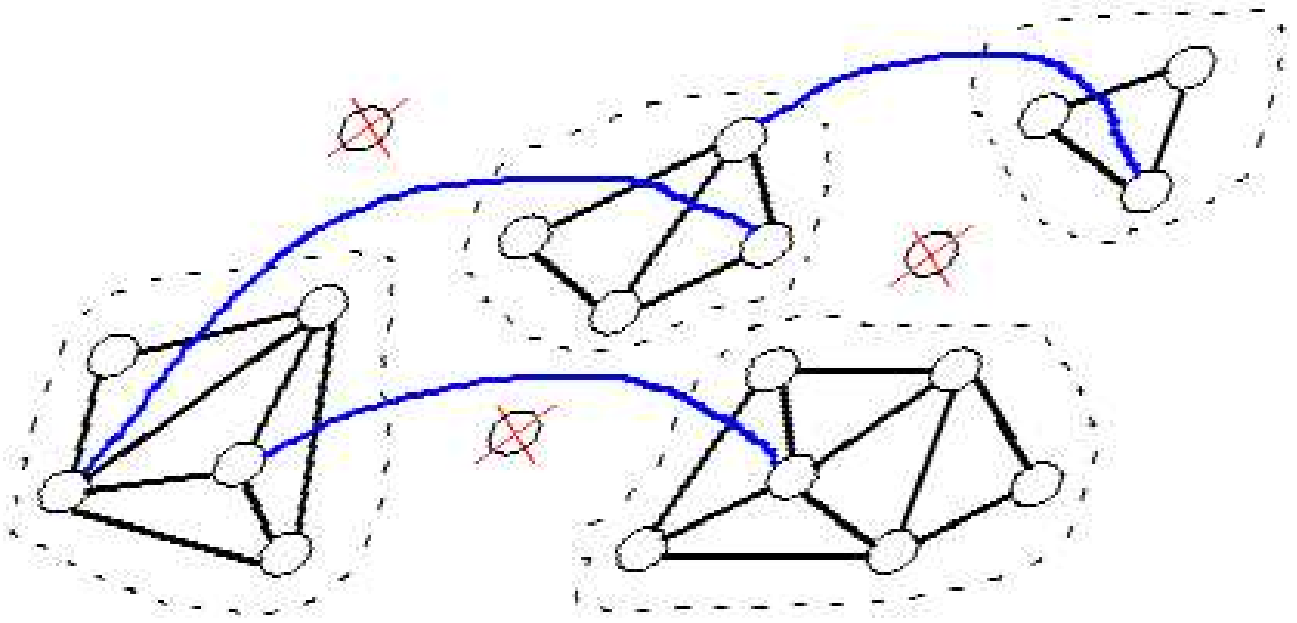


$\Rightarrow$ Selective reinforcement of perefered routes and removal of redundant links as the net. self-organization

A.Tero et al., Science 327, 439, 2010

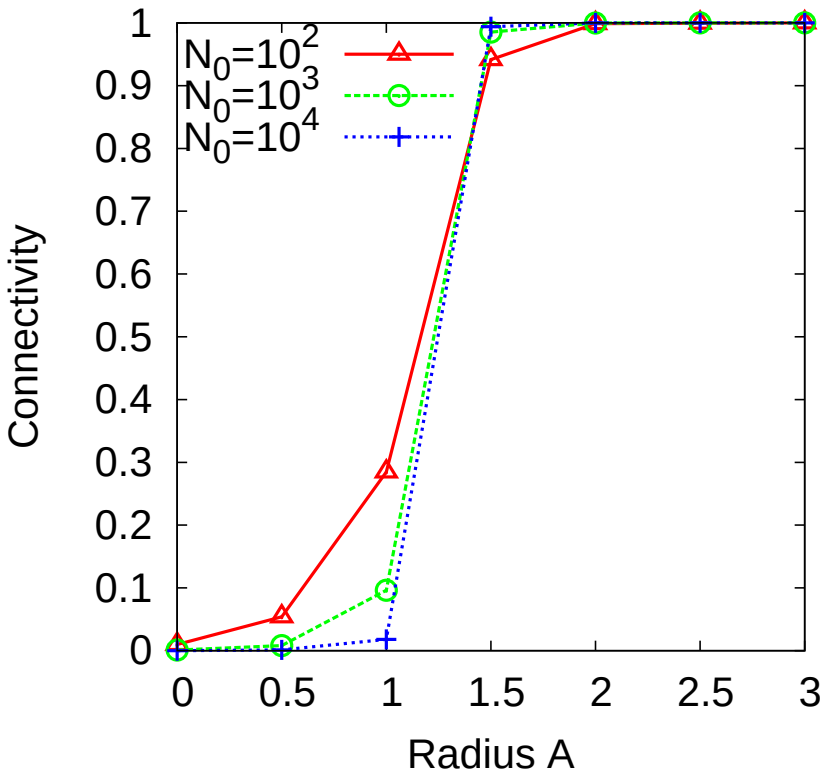
Remarkable 2

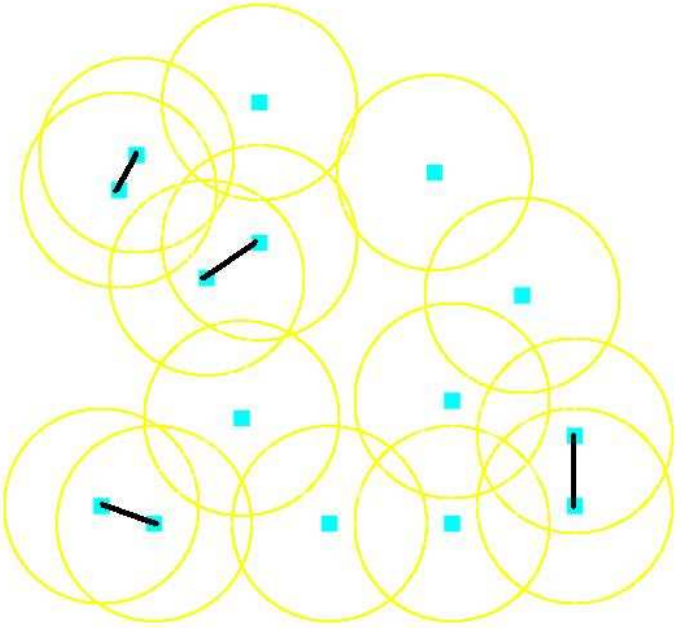
Shortcut effect on robustness in "long-distance relations" and "local or embedded relations"



Bridge local clusters: e.g. quick recover in the TOY-OTA supply-chain from the 1997 AISIN fire crisis, & rapid growth of Wenzhou people's economical nets.

Initial configuration





Unit disk graph

Wireless comm. model: UDG on a normalized square

Two nodes i and j are connected if $d_{ij} < A/\sqrt{N_0}$

$\Rightarrow \exists$ Phase transition of the conenctivity for the transmission radius A

Self-organized net. design

We assume that, for a packet transfer, the selection of a node as $source$ or $terminal$ is inhomogeneously proportional to the population in the territory of the nearest access from each mesh block
There are $R = 0.1N_T$ packets in the network

Link Survival If a packet pass a link e_{ij} on the (GPS-based) greedy routing, $w_{ij} \longrightarrow w_{ij} + 1$
With prob . $p_d = 0.01$ for all links, $w_{ij} \longrightarrow w_{ij} - 1$
Until $T = 3 \times 10^4$ steps, the increasing and the decreasing of w_{ij} are repeated

When $w_{ij} = 0$, the redundant link e_{ij} is removed, and isolated nodes without any links are also removed

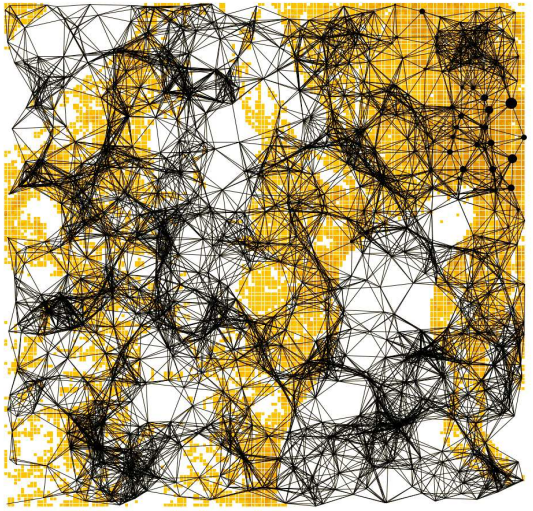
Adding shortcuts

In order to improve the robustness

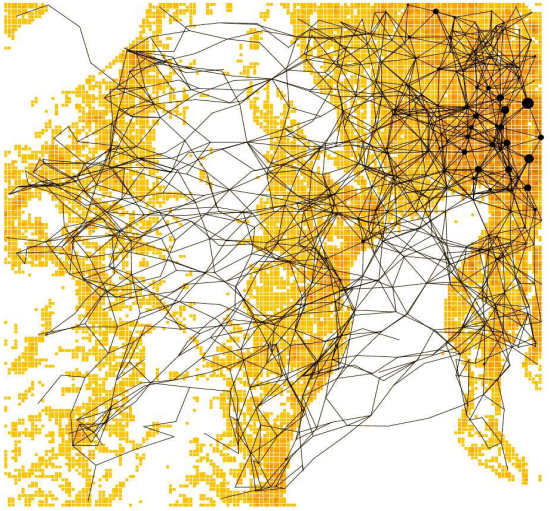
Path Reinforcement After stopping the removal of links at T, we continue the network generation and the transfer of packets to make 10 or 30% of shortcuts for the total number of survived links in the LS network
Each shortcut link is added due to the reinforcement between the current resident node of a randomly chosen packet and a randomly chosen node from the visited ones on the path

Random Shortcut On the LS network, we add 10 or 30% of shortcuts between randomly chosen two nodes independent from the positions of packets

Visualization



UDG

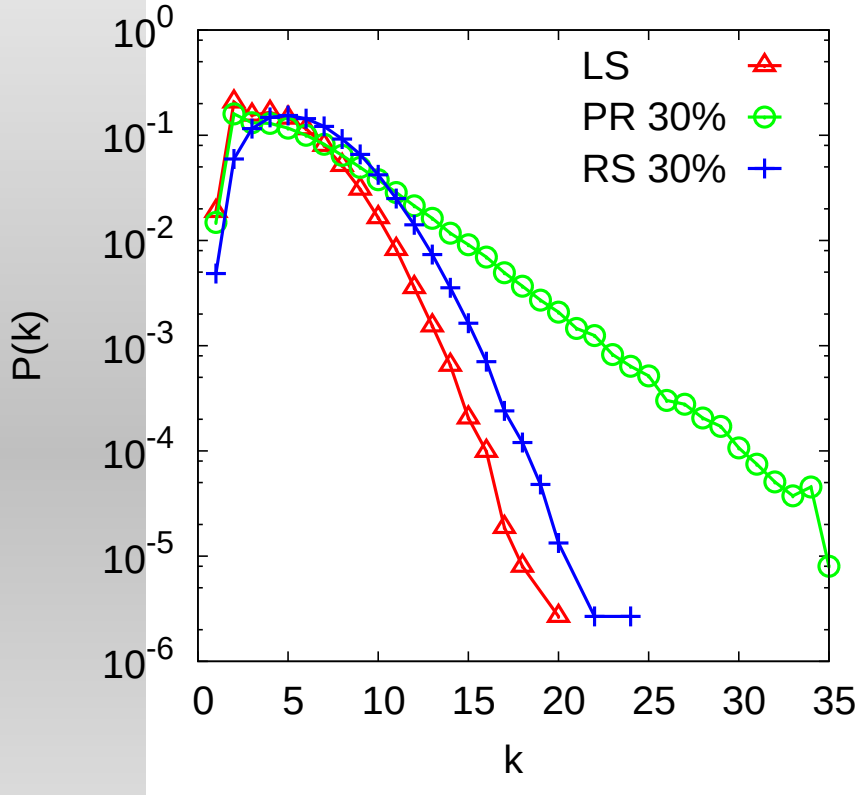


LS

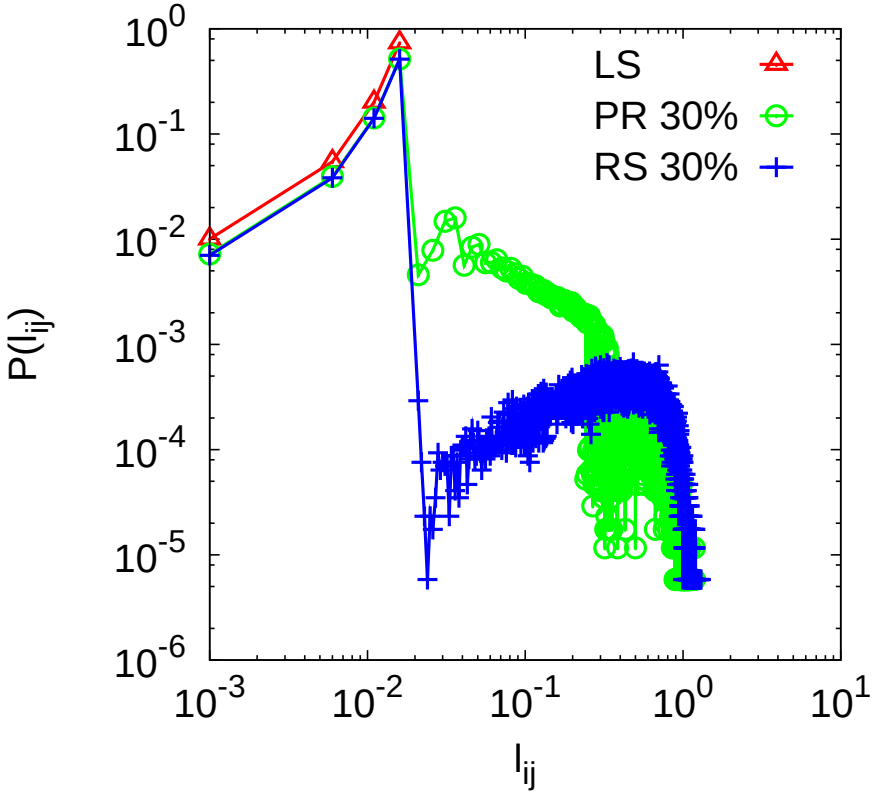
PR10%

RS10%

Structual properties w/o hubs



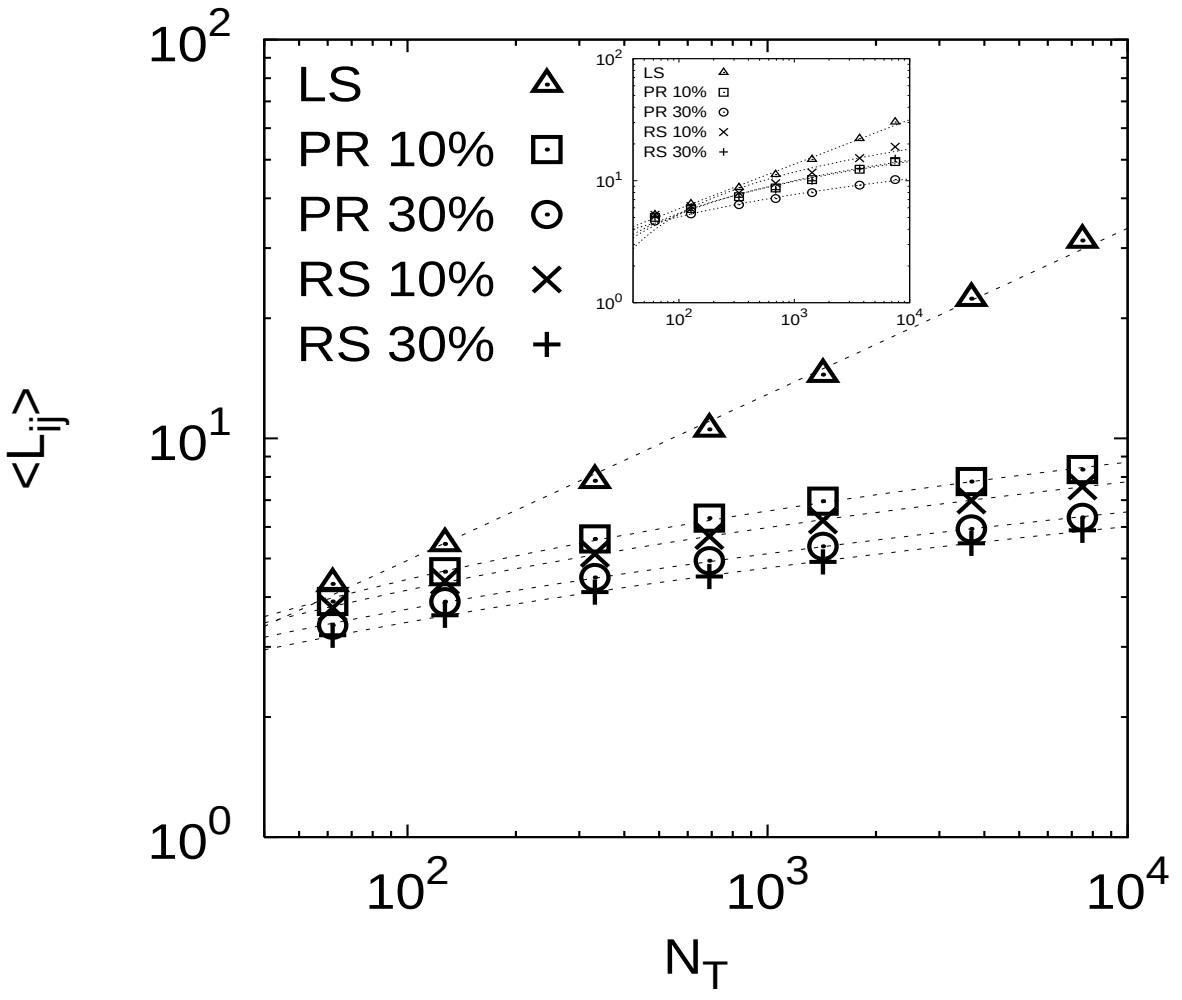
Degree



Link Length

$\Rightarrow$ Efficiently small degree $\langle k \rangle = 5 \sim 7$ and short link $\langle l_{ij} \rangle = 0.01 \sim 0.1$ even with shortcuts at $N_0 = 10^4$

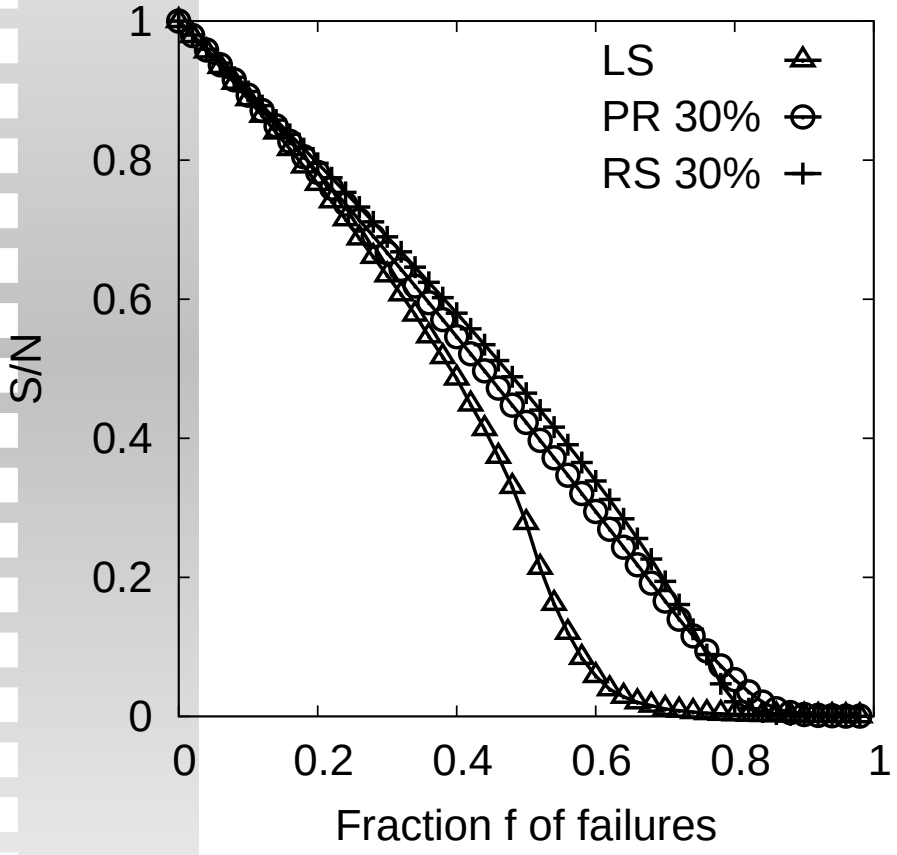
Ave. path length(hop-count)

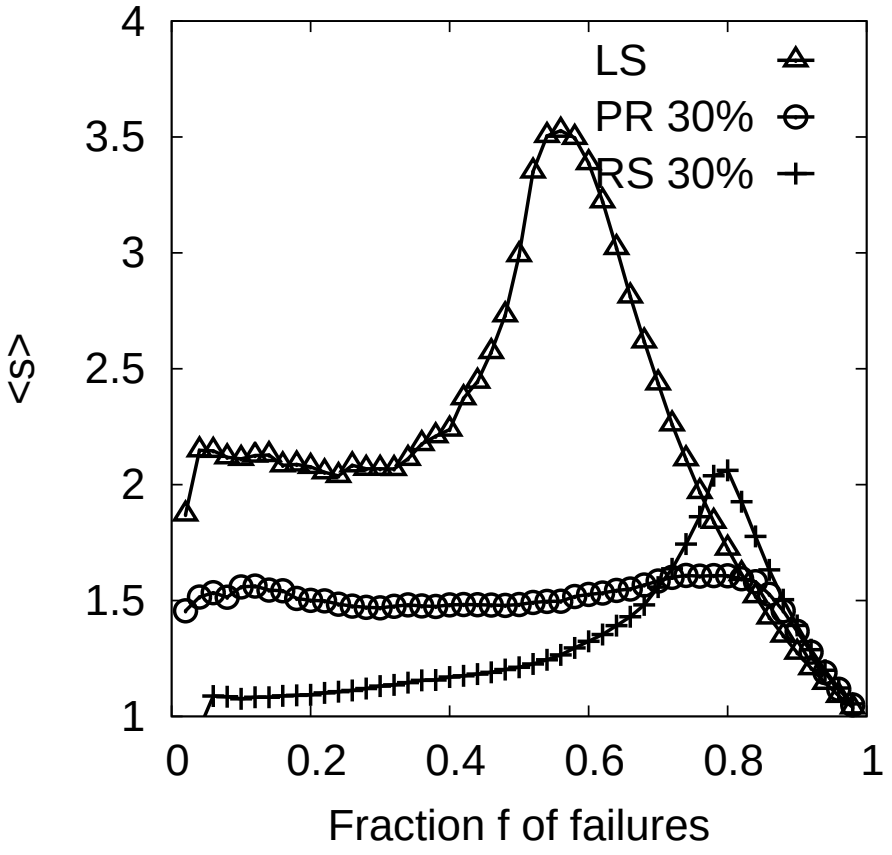


$\Rightarrow$ Improved from $O(\sqrt{N_T})$ in LS to $O(\log N_T)$ in PR and RS as the small-world effect !

Strong robustness -failures

Improved by adding shortcuts

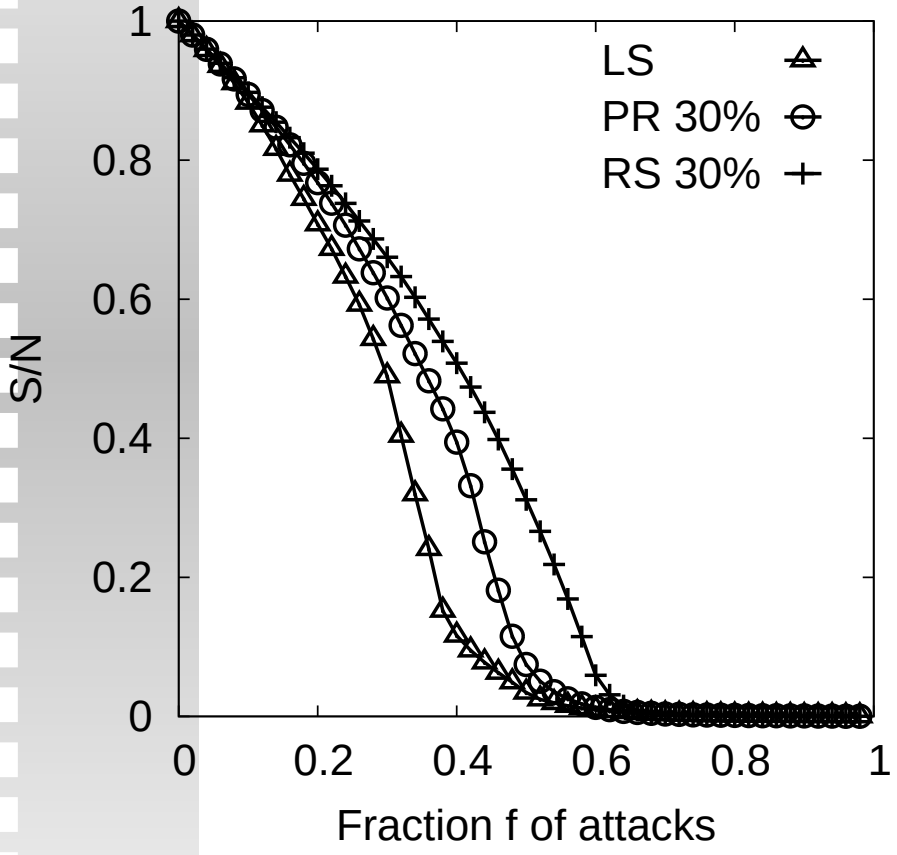


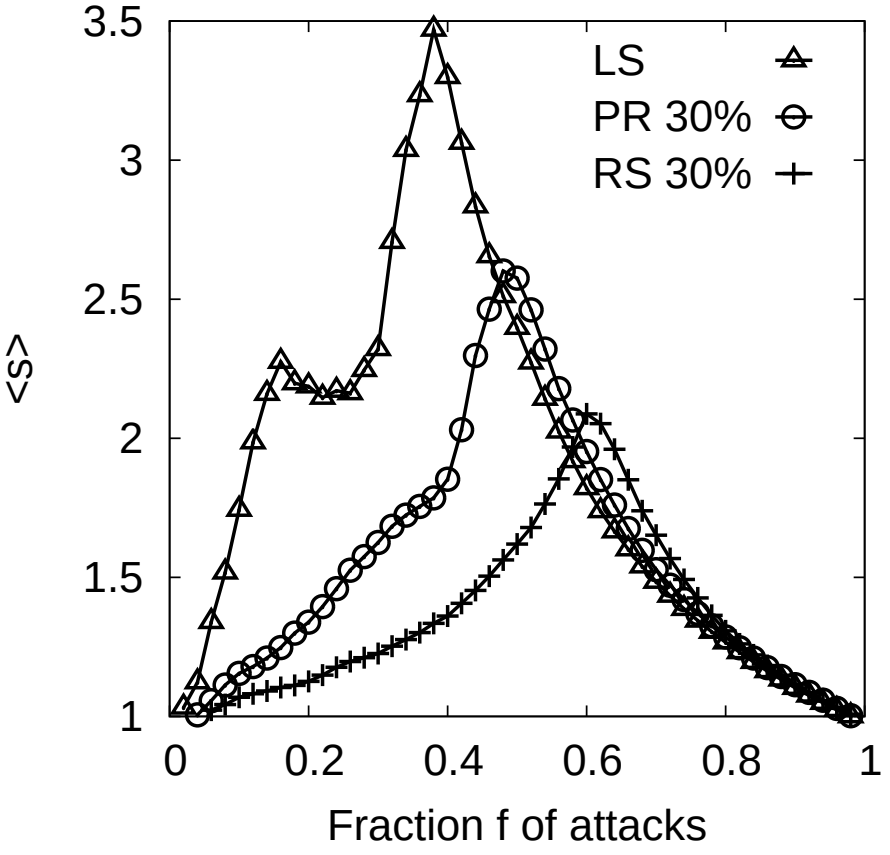


$\Rightarrow f_c$ is increased from 0.6 in LS to 0.8 in PR and RS

Strong robustness -attacks

Improved by adding shortcuts





$\Rightarrow f_c$ is increased from 0.4 in LS to 0.6 in PR and RS

Summary

- We propose self-organized geographical networks by link survival and adding shortcut
- The positions of survived nodes naturally concentrate on the areas of high pop.
- In particular, by adding shortcuts, the average number of hops is improved from $O(\sqrt{N_T})$ in LS networks to $O(\log N_T)$ as the small-world effect
- Moreover, for both failures and attacks, the robustness of connectivity becomes stronger

$\Rightarrow$ Thus, our self-organized networks keep the high comm. efficiency in realistic SF nets, but also overcome the vulnerability by the effects of shortcuts

For your kind attention

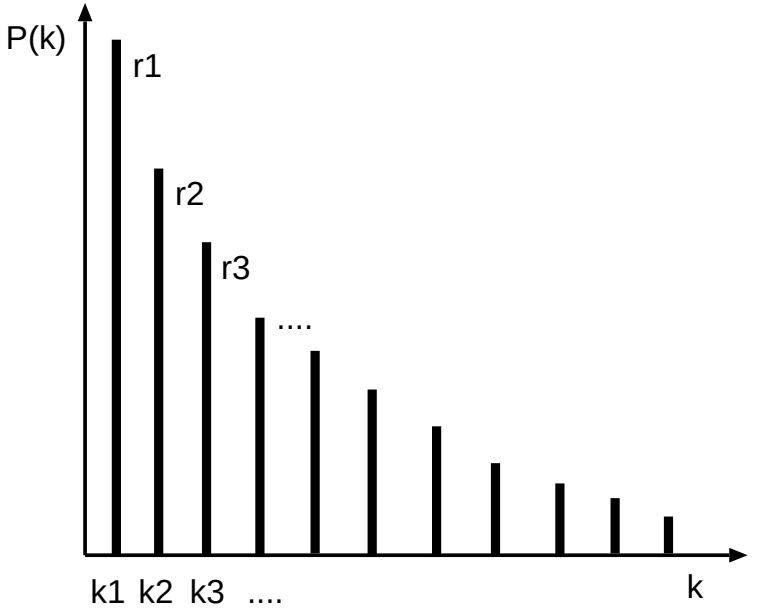
We will never forget your heart warming support!

A1. Optimal modality

In multimodal nets ($i = 1, 2, \ldots, M$ modalities):

$k_i \stackrel{\text{def}}{=} k_1 b^{i-1}$, $r_i \stackrel{\text{def}}{=} r_1 a^{i-1}$, $a > 1$, $0 < b < 1$,

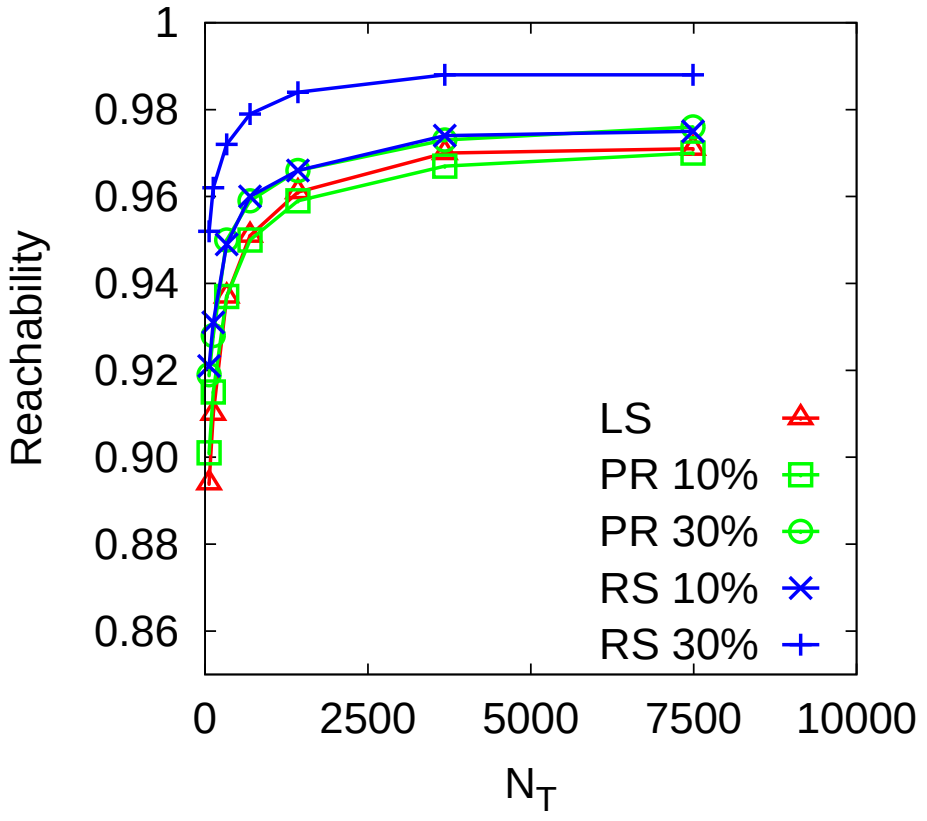
a bimodal net with k_1 and $k_2 = \sqrt{\langle k \rangle N}$ is the best for both failures and attacks, however a SF net at $M \to \infty$ is the worst



T.Tanizawa, G.Paul, S.Havlin, H.E.Stanley, Phys. Rev. E 74, 2006

A2. High reachability

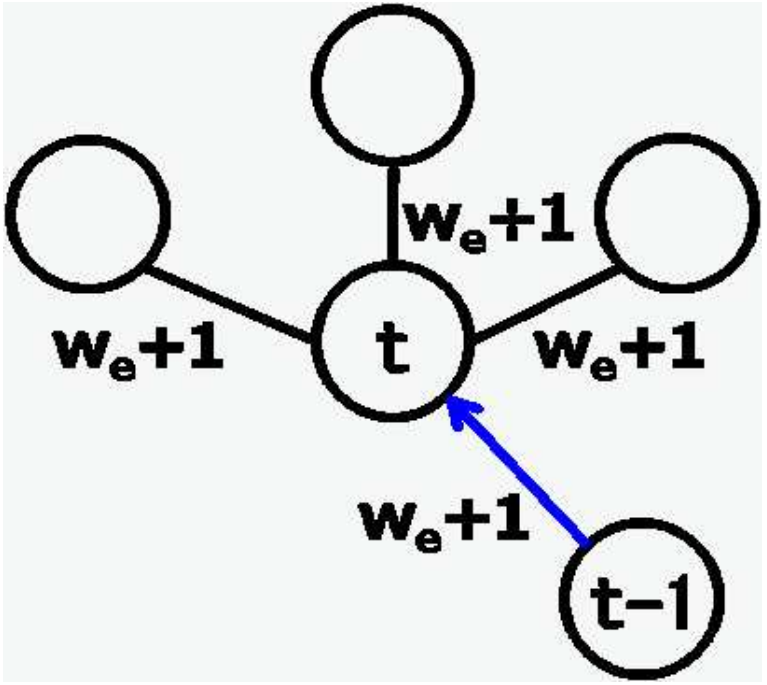
for the greedy routing with self-avoiding

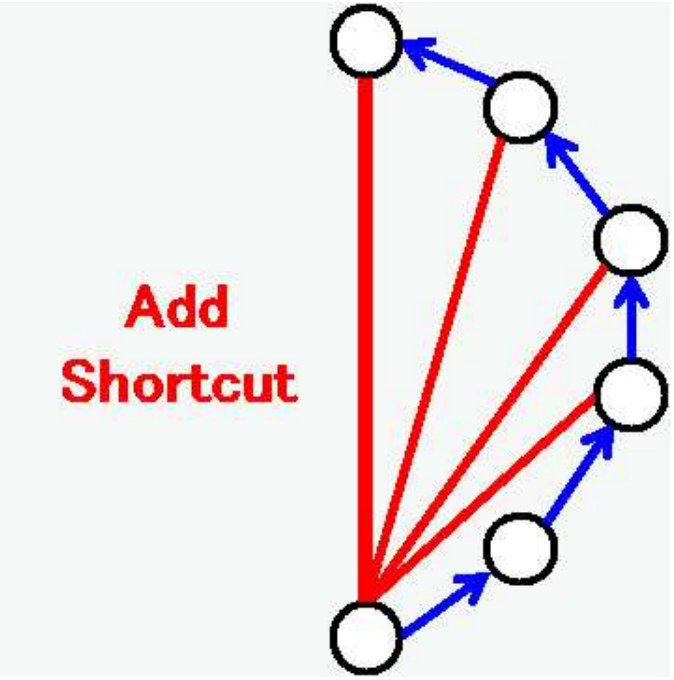


UDG	100	200	500	1000	2000	5000	10000
N_T	61.94	127.0	331.26	688.94	1425.4	3679.98	7489.92

A3. Coupled models

with network construction and flow dynamics





(Left) phase transition by the hub emergence

S.-W. Kim, J.D. Noh, PRE 80, 026119, 2009

(Right) quasi-complete graph on 1D, SF net on 2D

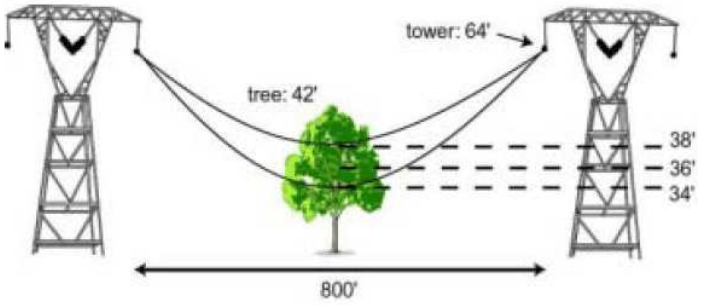
N.Ikeda, Physica A 379, 701, 2007

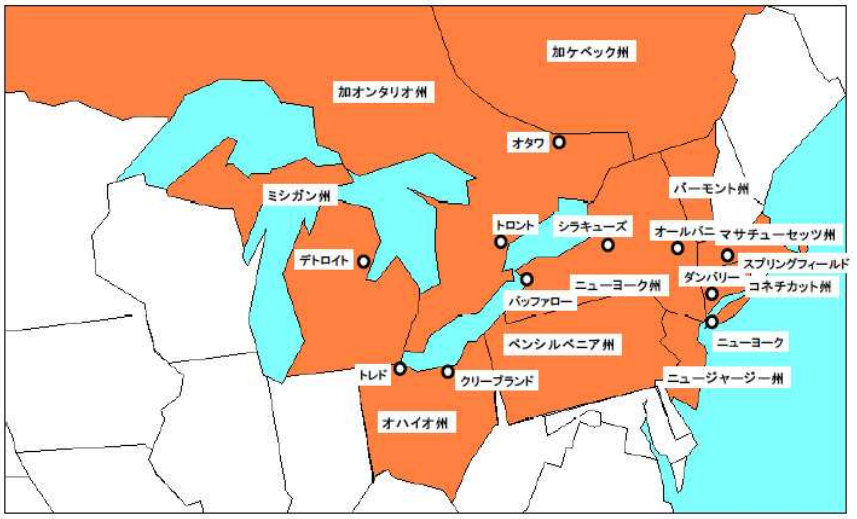
A4. Cascading failure

If the e-power or the flow exceeds the node or link capacity

∃ same mechanism in:

- crisis of power-grid from initial disconnections to wide area blackout
- congestion in traffic and Internet
- ⋮





NERC "August 14 2003 Blackout"

A5. Trends of mega-city hazards

- Mixes of natural, technological, and social hazards are increasingly common
- Risks are changing slowly
- Loci of hazards are shifting markedly
- Differentially vulnearable groups are becomming polarized and segregated
- Public support for hazard-management initiatives may be faltering
- Overlaps among hazard and urbanization issues offer opportunities for managerial intervention

J.K.Michell ed., Crucibles of hazard: Mega-cities and disasters in transition, Chap.13, United Nations University Press, 1999