SIEMENS

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Selforganizing control of network structure in wireless communication

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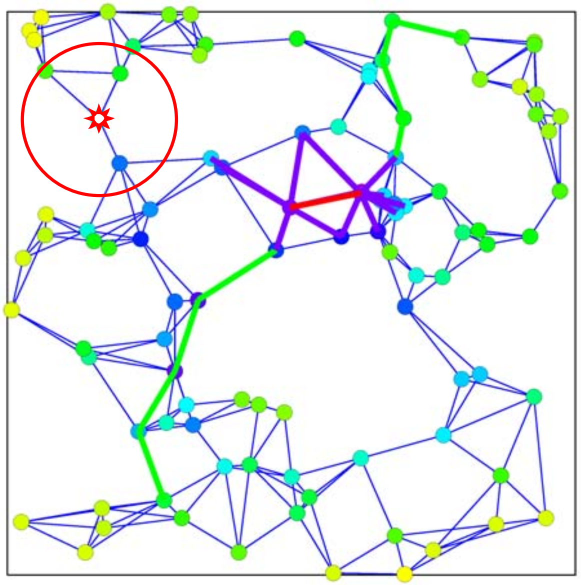

Wireless multihop ad hoc networks:

- **nodes:** distributed in space
- **(wireless) links:** links inside transmission radius
- **routing:** packet traffic hops along end-to-end communication routes
- **medium access control:** neighbors are blocked during an active one-hop transmission
- no infrastructure, no central master

SELFORGANIZATION:

- networks – structure, dynamics & function
- protocol-design concepts – distributive, adaptive & learning

TOPICS:

- (strong) network connectivity
- (power efficiency)
- (large) end-to-end throughput capacity
- (efficient) routing & congestion control

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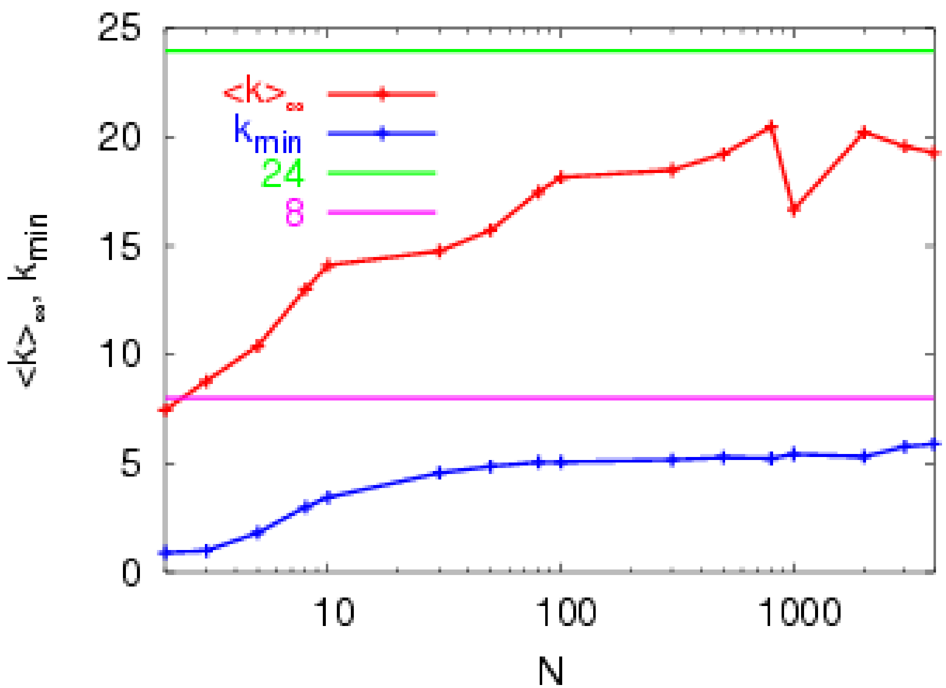
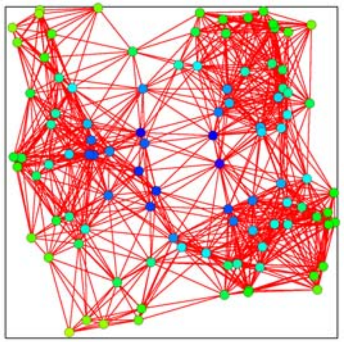
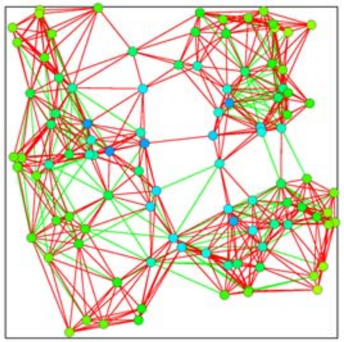
Connectivity: minimum-node-degree rule





$$P_i = P = const$$

$$ngb \geq ngb_{min}$$



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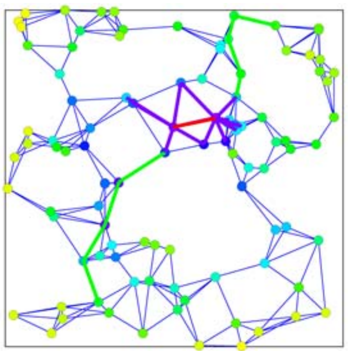
follow-up: Montemanni+Gambardella'05

Capacity (throughput) I: simple estimate

$$T_{e2e} = \frac{1}{D} \frac{N}{MAC}$$

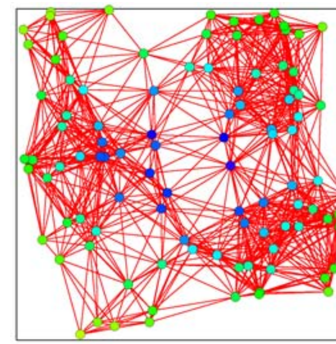


Gupta+Kumar'00

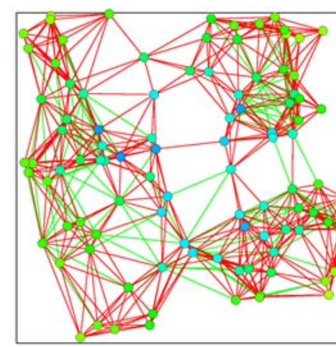
$$T_{e2e} \propto \sqrt{N}$$

$$\begin{array}{ll} N < N_{crit} : & \text{cellular}\left(T_{e2e} = 0.5\right) \\ N > N_{crit} : & \text{multihop ad hoc} \end{array}$$

emergence of frustration



small D, large MAC



large D, small MAC

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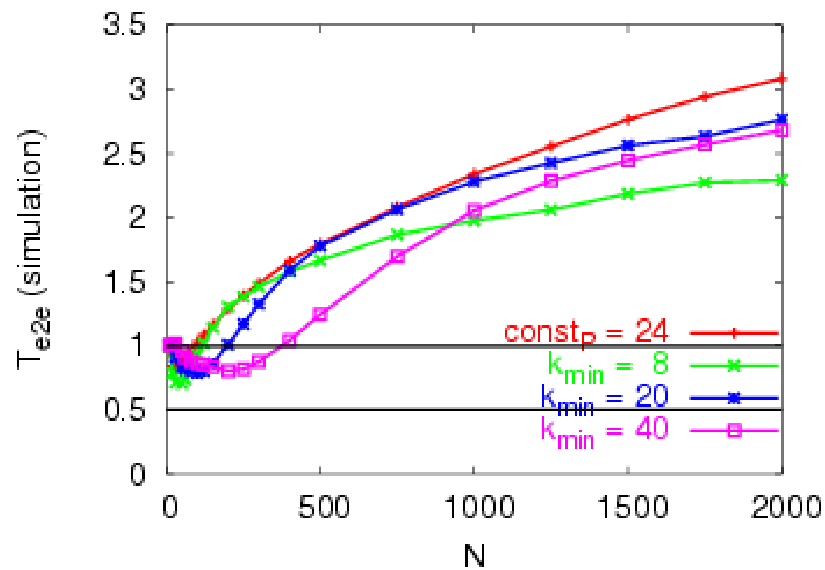
Throughput II: packet traffic simulation

- discrete-time-step dynamics
- random packet traffic
- source load μ
- shortest-path routing
- MAC blocking
- infinite buffers (FIFPO)

$$\mu_m^{in} = \mu_m^{out} \Rightarrow \mu_m^{crit}$$

$$\mu_{crit} = \min_m \mu_m^{crit}$$



$$T_{e2e} = \mu_{crit} N \propto N^{\gamma}$$

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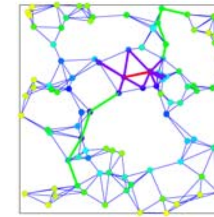
Throughput III: most-critical-node effect



$$\mu_m^{in} \le \mu_m^{out}$$

$$\mu_m^{in} = \mu N B_m^{node} / N(N-1)$$

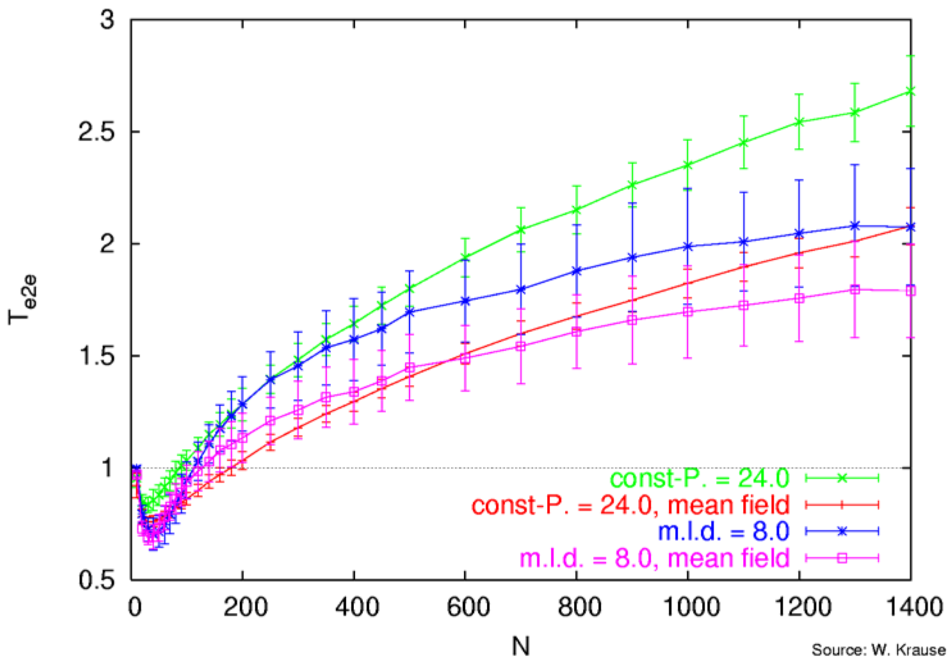
$$B_m^{node} = \sum_{i,f} \mathrm{route}(i \to f; m)$$

$$\mu_m^{out} = 1 / t_m^{out}$$

$$t_m^{out} = 1 + \Delta t_1 + \Delta t_2$$

$$\Delta t_1 = \sum_1 p(n_1 \ge 1)$$

$$\Delta t_2 = \sum_2 p(n_2 \ge 1) \sum_1 \frac{B_{21}^{link}}{2 B_2^{node}}$$



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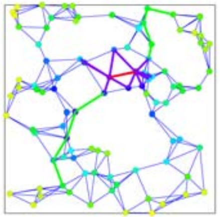
Throughput IV: intuitive guess



$$\mu_m^{in} = \mu N B_m / N(N-1)$$

$$B_m = \sum_{i,f} \mathrm{route}(i \to f; m)$$

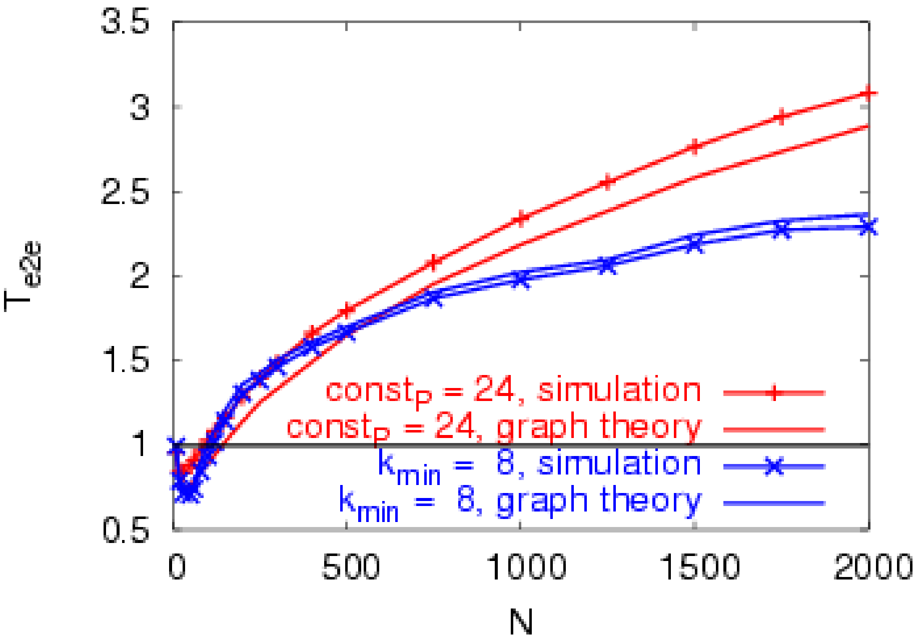
$$\mu_m^{out} = 1 / t_m^{out}$$

$$t_m^{out} = B_m^{cum} / B_m = \left(B_m + \sum_{n \in ngb(m)} B_n\right) / B_m$$

$$\mu_m^{in} \le \mu_m^{out}$$

most-critical-node effect:

$$T_{e2e} \approx \frac{N(N-1)}{\left\langle \sup_m B_m^{cum} \right\rangle}$$

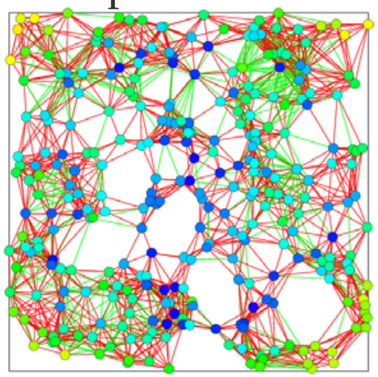


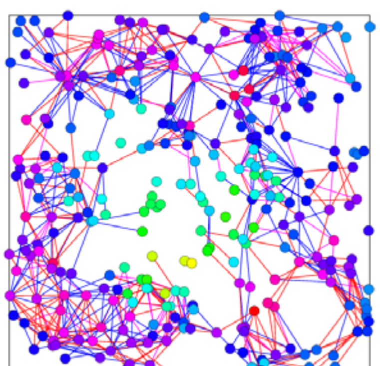
arXiv:cs.NI/0503010

Throughput V: topology optimization

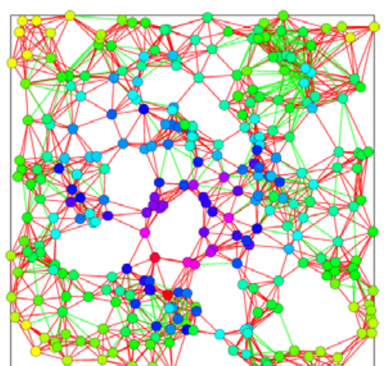
$$T_{e2e} = \frac{N(N-1)}{\left\langle \sup_m B_m^{cum} \right\rangle}$$

optimized

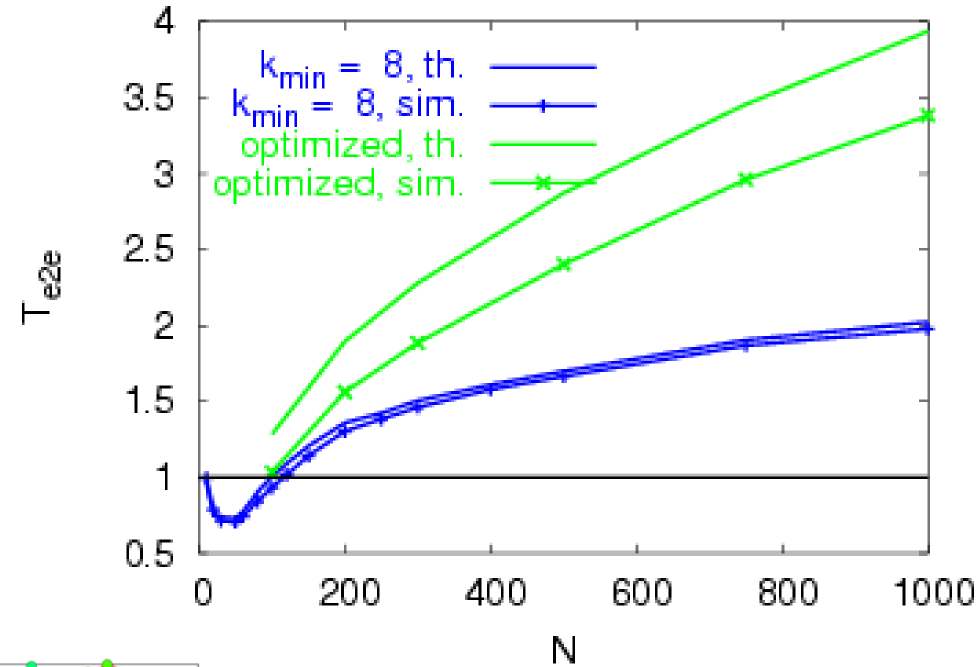




changes



initial (ngb=8)



(distributive) outlook: network design game

$$\pi_i = \left(\sum_f d_{if}\right)^{-1} - \alpha P_i$$

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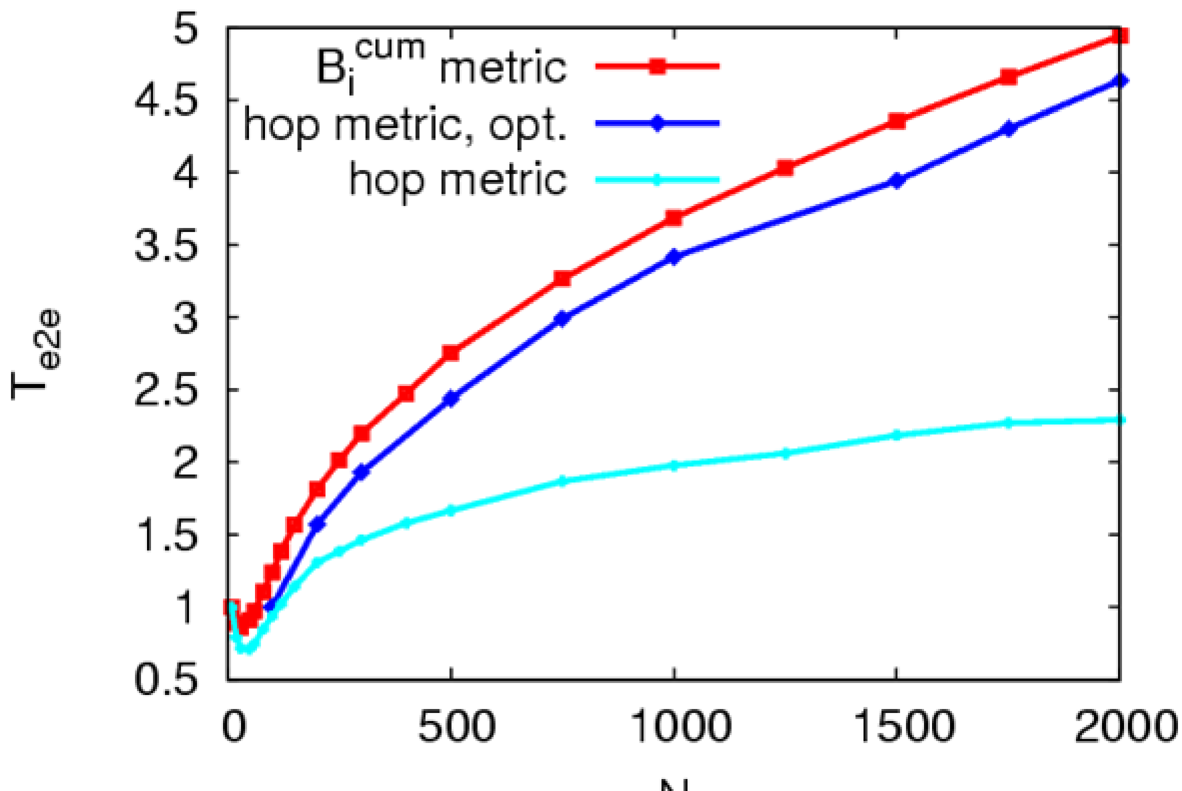
Routing & congestion control I: proactive routing metric

$$B_m = \sum_{i,f} \mathrm{route}(i \to f; m)$$

$$B_m^{cum} = B_m + \sum_{ngb} B_{ngb}$$

$$d_{i \to f} = \sum_m \mathrm{route}(i \to f; m)\, B_m^{cum}$$



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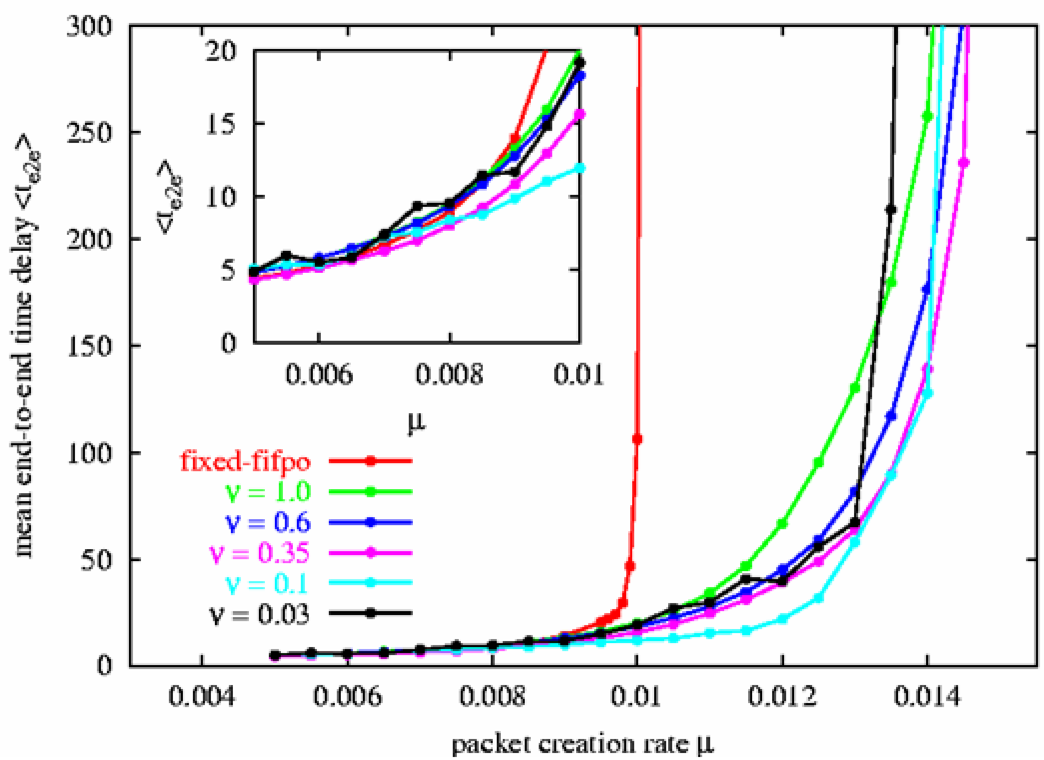
Routing & congestion control II: reactive reinforcement

$$W_{if,j} \leftarrow (1-\nu)\, W_{if,j} + \nu \left[w_{ij} + \left(\min_{k \in ngb(j)} W_{jf,k} \right) \right]$$



$$w_{ij} = (n_j \mp 1) + 1$$

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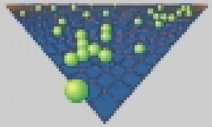

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Outlook: more selforganization

(from centralized to decentralized control)

- **network structure:**
  network design games
- **network dynamics**
- **network function:**
  computing,
  learning,
  controlling, …

technology meets biology

network design principles:

selforganization, robustness, flexibility, …

biology:

Physica A 350 (2005) 622
M. Kuhnt (Dipl.)

brain,
regulatory molecular networks,
immune system, …

engineering:

communication networks,
sensor & actuator networks,
power internet, …