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# Selforganizing control of structure and dynamics in wireless ad hoc networks

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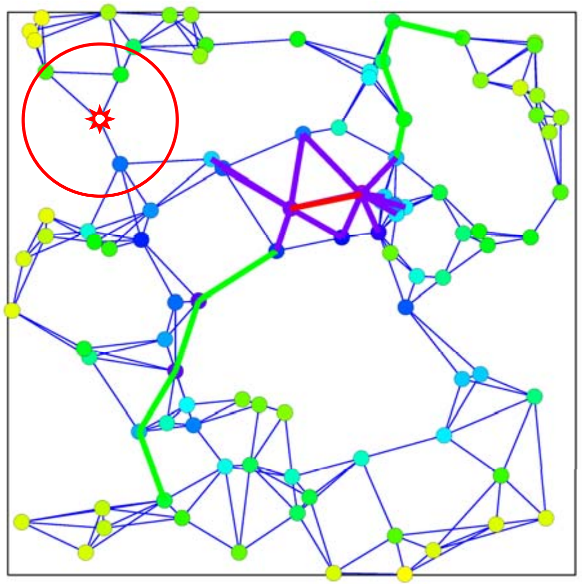

## Wireless multihop ad hoc networks:

- **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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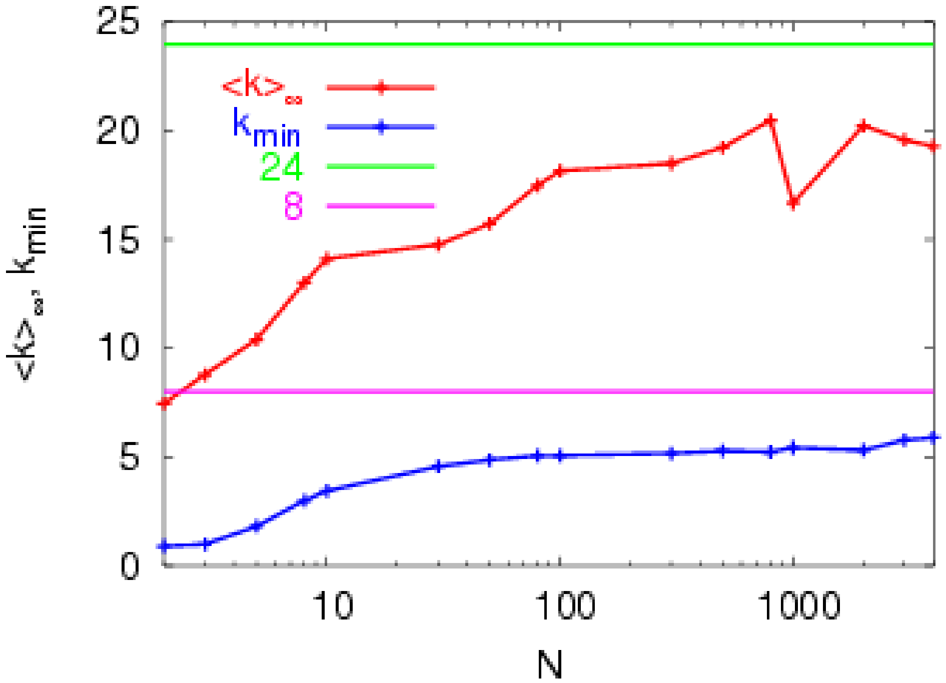
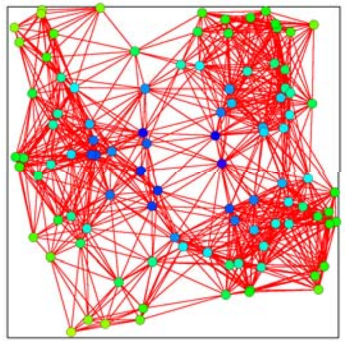
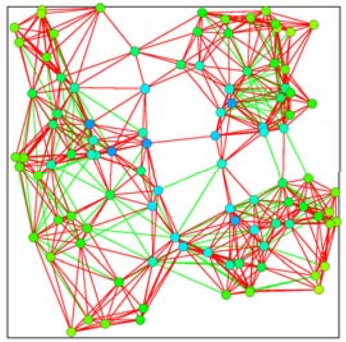
# Connectivity: minimum-node-degree rule



$P_i = P = const$

$ngb \geq ngb_{min}$

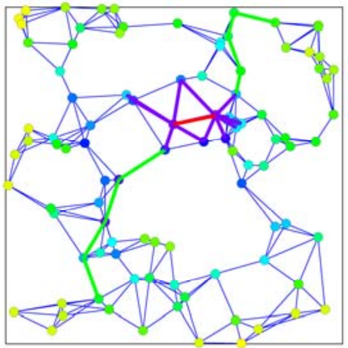


**Physica A 325 (2003) 577**

**follow-up: Montemanni+Gambardella'05**

# Capacity (throughput) I: simple estimate

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

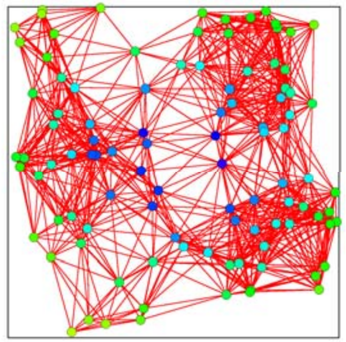


Gupta+Kumar'00

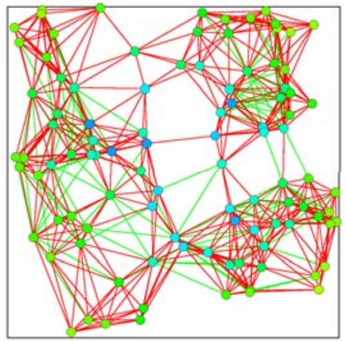
$$T_{e2e} \propto \sqrt{N}$$

$$N < N_{crit} : \quad \text{cellular} \left( T_{e2e} = 0.5 \right)$$
$$N > N_{crit} : \quad \text{multihop ad hoc}$$

**emergence of frustration**



small D,
large MAC



large D,
small MAC

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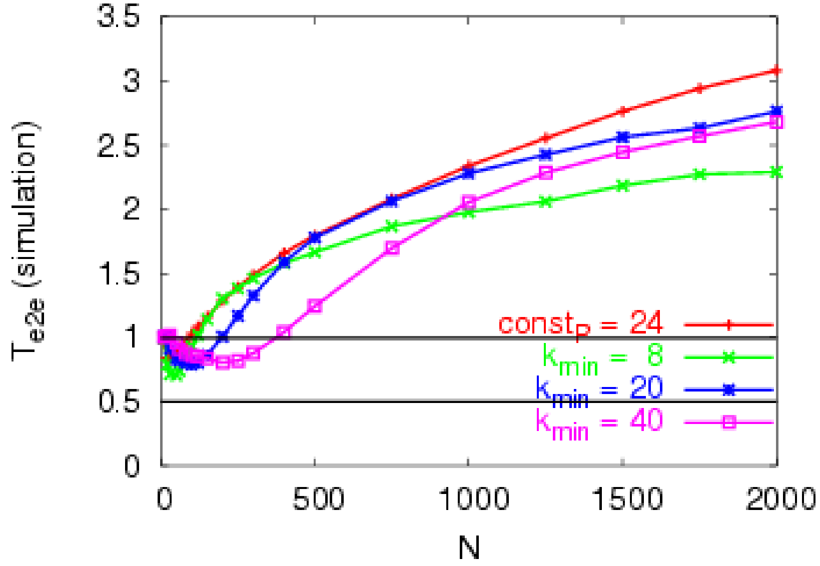
Physica A 338 (2004) 633

# Throughput II: packet traffic simulation

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

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

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




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

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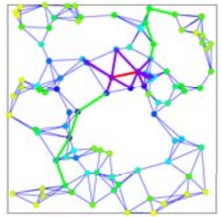
# Throughput III: intuitive guess



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

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

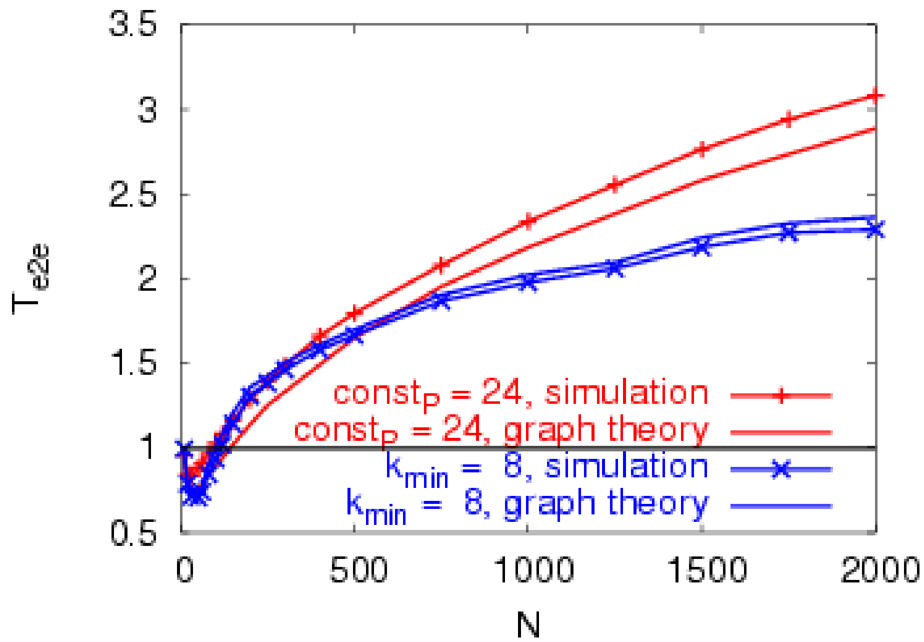
$$\mu_m^{out} = 1/t_m^{out}$$

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

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

**most-critical-node effect:**

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

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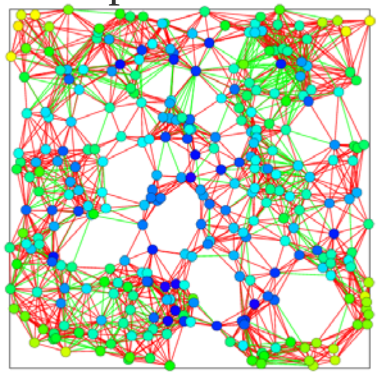
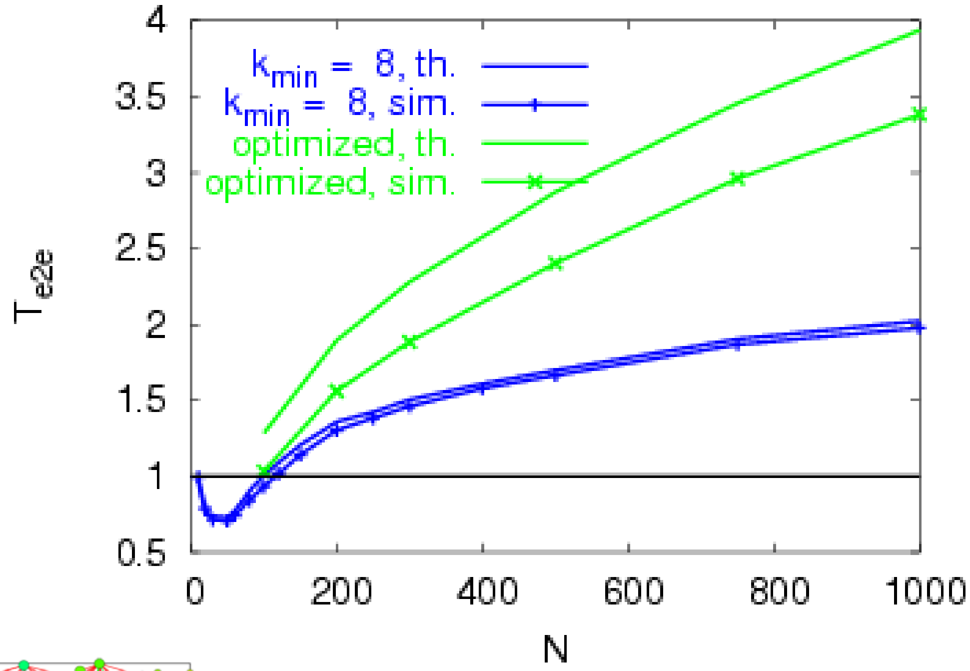
arXiv:cs.NI/0503010

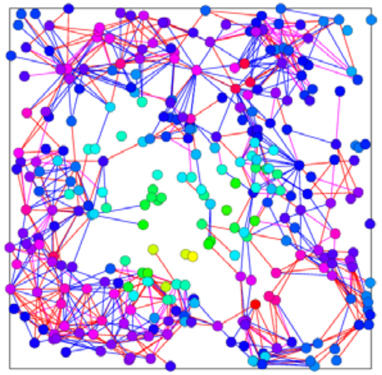
# Throughput V: topology optimization

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

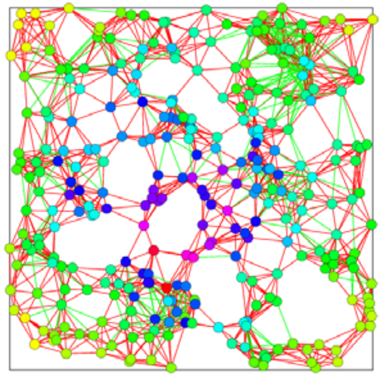
optimized





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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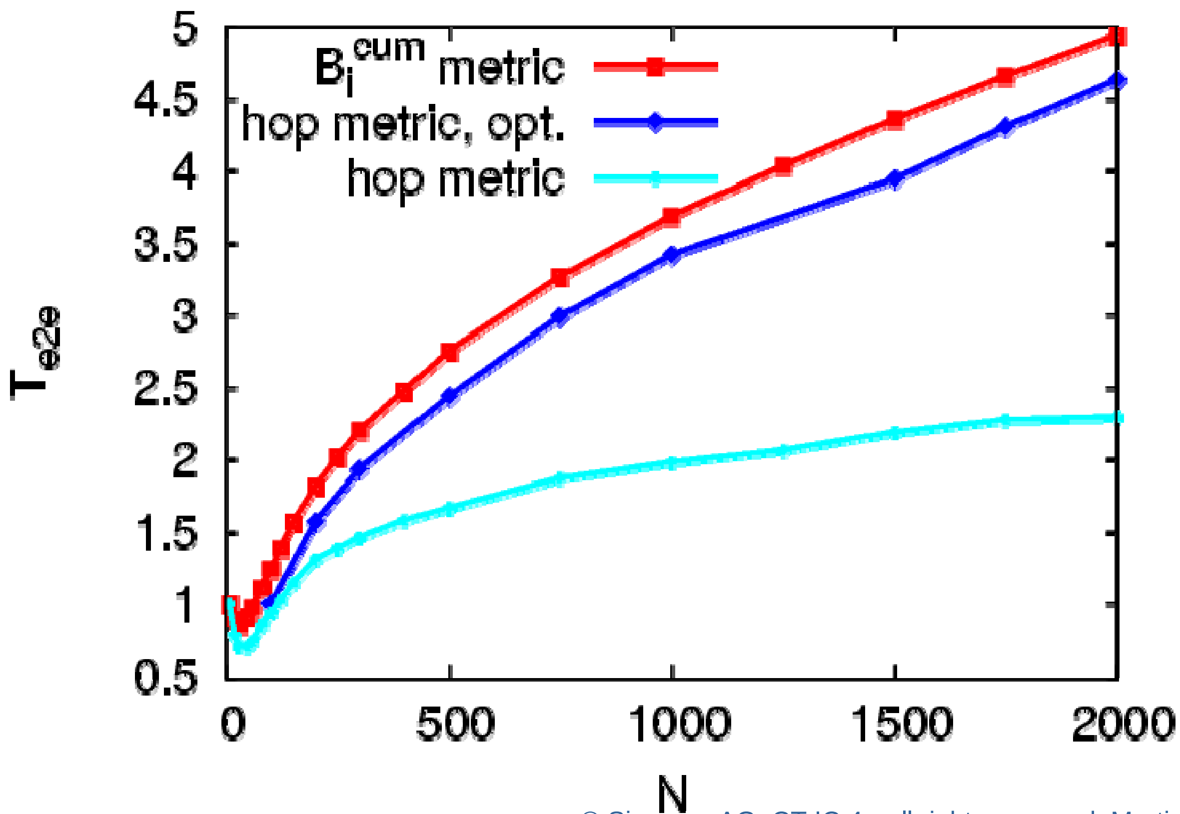
Physica A, in press

# Routing & congestion control I: proactive routing metric

$$B_m = \sum_{i,f} \text{route}(i \rightarrow f; m)$$

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

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



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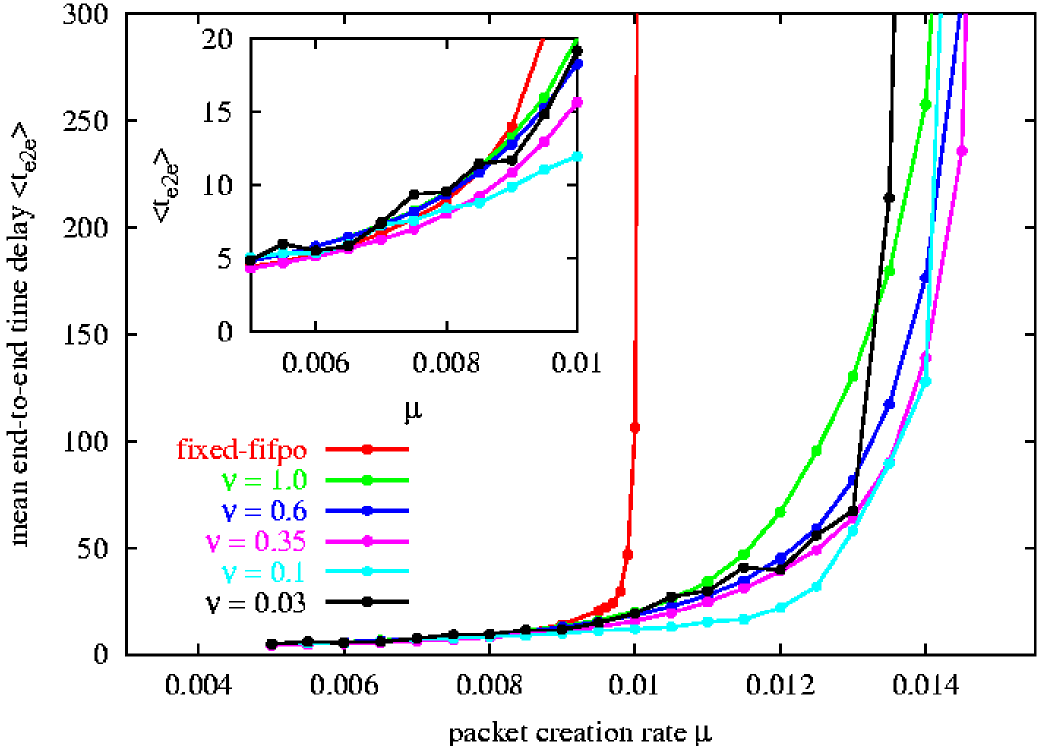
# Routing & congestion control II: reactive reinforcement

Physica A 341 (2004) 677

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

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

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# 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**

*brain,*
*regulatory molecular networks,*
*immune system, …*

**engineering:**
*communication networks,*
*sensor & actuator networks,*
*power internet, …*