Selforganizing control of structure and dynamics in wireless ad hoc networks

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
Connectivity: minimum-node-degree rule

\[
P_i = P = \text{const}
\]

\[
ngb \geq ngb_{\text{min}}
\]

Physica A 325 (2003) 577
follow-up: Montemanni+Gambardella'05
Capacity (throughput) \( I \): simple estimate

\[ T_{e2e} = \frac{1}{D \cdot MAC} \]

\[ T_{e2e} \propto \sqrt{N} \]

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

Gupta+Kumar'00

emergence of frustration

- small \( D \), large MAC
- large \( D \), small MAC

© Siemens AG, CT IC 4 - all rights reserved, Martin Greiner, 18.07.2005
Throughput II: packet traffic simulation

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

$\mu^{in}_m \leq \mu^{out}_m \Rightarrow \mu^{crit}_m$

$\mu^{crit} = \min_m \mu^{crit}_m$

$T_{e2e} = \mu^{crit} N \propto N^{\gamma}$
**Throughput III: intuitive guess**

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

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

\[
\mu_m^{out} = 1 / t_m^{out}
\]

\[
t_m^{out} = B_m^{cum} / B_m = (B_m + \sum_{n \in \text{neigh}(m)} B_n) / B_m
\]

\[
\mu_m^{in} \leq \mu_m^{out}
\]

**most-critical-node effect:**

\[
T_{e2e} \approx \frac{N(N - 1)}{\sup_m B_m^{cum}}
\]
**Throughput V: topology optimization**

\[ T_{\text{e2e}} = \frac{N(N-1)}{\langle \sup_m B_m^{\text{cum}} \rangle} \]

*(distributive) outlook: network design game*

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

© Siemens AG, CT IC 4 - all rights reserved, Martin Greiner, 18.07.2005
Routing & congestion control I: proactive routing metric

\[ d_{i \rightarrow f} = \sum_m \text{route}(i \rightarrow f; m) B_{m}^{\text{cum}} \]

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

\[ B_{m}^{\text{cum}} = B_m + \sum_{\text{ngb}} B_{\text{ngb}} \]
Routing & congestion control II: reactive reinforcement

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

\[ w_{ij} = (n_j + 1) + 1 \]
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:
brain, regulatory molecular networks, immune system, ...

engineering:
communication networks, sensor & actuator networks, power internet, ...

© Siemens AG, CT IC 4 - all rights reserved, Martin Greiner, 18.07.2005