Design Principles for Mobile Computing and Communication Systems

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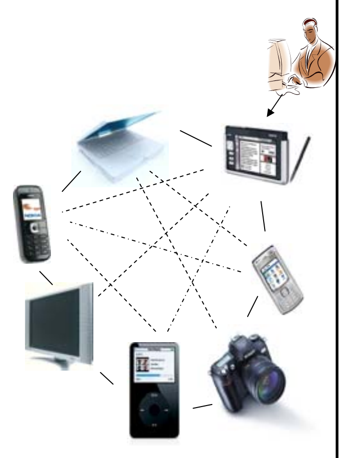
Introduction and Overview

- Nokia Research overview
- Networking moving to distributed control
  - System design moving from centralized to distributed
  - Reduce cost of operation
  - Emerging pervasive networks
- 4 design paradigms for self-organization
  - Based on analysis of existing protocols
- Two examples in multi-hop wireless networks
  - Distributed resource control in multi-hop networks
  - Gateway discovery and multi-hop handover
- New challenges for emerging ubiquitous networks
  - From distributed to self-organized system design



Main reference: Christian Prehofer, Christian Bettstetter, **Self-Organization in Communication Networks: Principles and Design Paradigms**, IEEE Communications Magazine, July 2005.

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Definitions of Self-organization

- **Merriam-Webster:**
  1 : organization of oneself or itself
  2 : the act or process of forming or joining an organization (as a labor union).
- **Wikipedia:** Self-organization is a process in which the internal organization of a system, normally an open system, increases in complexity without being guided or managed by an outside source. Self-organizing systems typically (though not always) display emergent properties.
- **Chemistry:** The capability of ... spontaneously generate a well-defined supramolecular entity by self-assembling from components in a given set of conditions
- **Economics:** A market economy is sometimes said to be self-organizing.
- "We define a self-organizing system as one where a collection of units coordinate with each other to form a system that adapts to achieve a goal more efficiently."

Self-X

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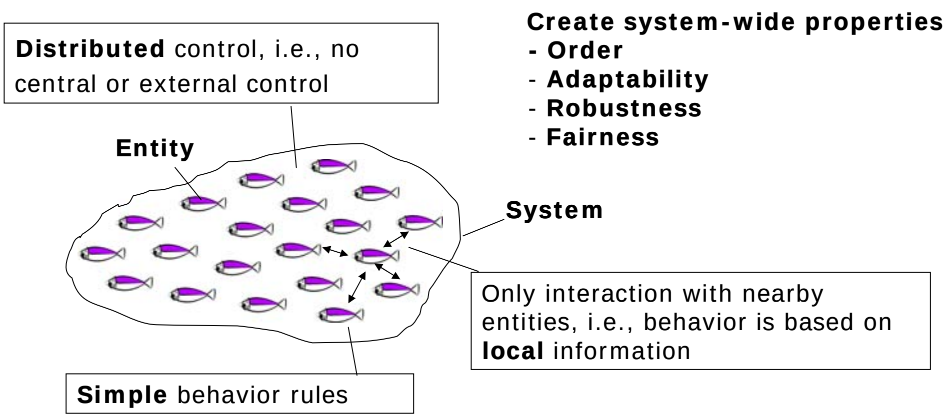
Self-organization in Networking



- Need to understand typical „design patterns“ of self-organization
- Need to understand scope – which functions to be self-organized

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Summary of Paradigms and Examples

Paradigms

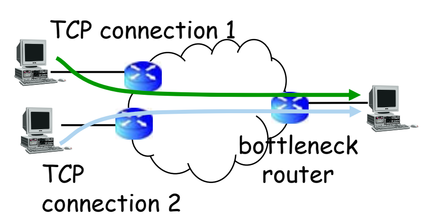
1. Achieve global properties with local behavior
2. Do not aim for perfect coordination
   - Implicit coordination
3. Minimize long-lived state
4. Adaptation

Examples

- Addressing and Naming
  - IPv6, ad-hoc networks
- Resource and congestion control and access
  - TCP
  - Medium Access (MAC) protocols
  - **Distributed resource control in multi-hop networks**
- Resource discovery
  - **Proactive and reactive discovery**
  - **Multi-hop handover**
- Data collection in pervasive networks

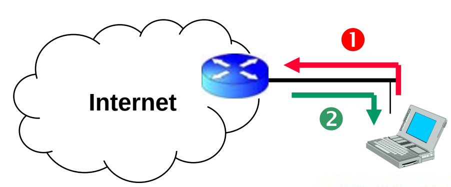
Paradigm #1: Achieve Global Properties with Local Behavior

- Behavior rules based on local environment
  - Don't need to know about global state
- No need for central control
- System-wide property from local behavior



Examples

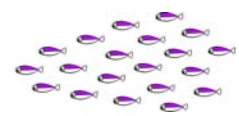
- **TCP protocol** for Internet congestion control
  - TCP is fully distributed, very simple, flexible
    - End-points control resources in the network
  - TCP achieves „fair“ resource distribution
- **Addressing** in the Internet – IPv6
  - Stateless autoconfiguration
  - Assign a globally unique address
  - Hosts configure address themselves
    - Global Address = Network prefix + Interface ID



Router Solicitation and Router Advertisement with Network prefix

From Local Behavior to Self-organization

Some typical questions



- Local behavior and control are important – but does it work?
- When does local behavior lead to optimal solutions?
  - But optimal solutions are difficult in dynamic networks
- Local behavior rules may lead to inconsistencies
  - When is this preferable or acceptable?

Example for addressing

- **Passive autoconfiguration** for ad-hoc networks
  - Assign addresses locally based on local information
  - Maintain list of assigned addresses locally
    - Passively collect information about already assigned & used addresses
  - Detect address conflicts in a timely manner locally

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Paradigm #2: Do not Aim for Perfect Coordination: Implicit Coordination

„Talking is silver, silence is golden"

- Robustness often more important than perfect or optimal solution
- When can we admit inconsistencies?
  - Need to be detectable or contained
- What is implicit coordination?
  - E.g. Listening and observing, randomization
  - No explicit signaling, no dedicated, central controllers

Examples

- TCP way of implicit communication: packet loss
- Local address assignment: Usage of passive duplicate address detection
- WLAN MAC protocols with Carrier Sense Multiple Access
- Distributed resource control in multi-hop networks
  - Listening and overhearing to minimize control messages

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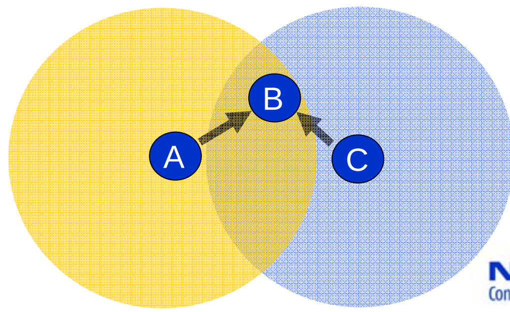
Example

WLAN MAC Protocol with Implicit Communication

- How to split resources of a shared (wirless) medium?
- Carrier Sense Multiple Access / Collision Detection, (IEEE 802.11 CSMA / CD)
- „The CSMA/CD protocol functions somewhat like a dinner party in a dark room"
  - Charles Spurgeon
- E.g. A and C send data at same time to B => Collision
  - A and C may not hear each other
- Collision events give information about status of the network
  - Capetanakis, 1979
- Random backoff after collision



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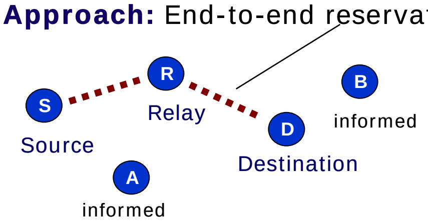
Example

DARE: Distributed Resource Control in Multi-hop Networks

Goal: Extend WLAN 802.11 MAC to make it suitable for

- Resource allocation for real–time applications
- Distributed control of multi-hop reservations

Approach: End-to-end reservation of resources (time slots)



Protocol: DARE

Distributed allocation of time slots for real-time traffic end-to-end

E. Carlson, C. Prehofer, C. Bettstetter, H. Karl, A. Wolisz.
A Distributed End-to-End Reservation Protocol for IEEE 802.11-based Wireless Mesh Networks.
IEEE Journal on Selected Areas in Communications (JSAC), 2006.

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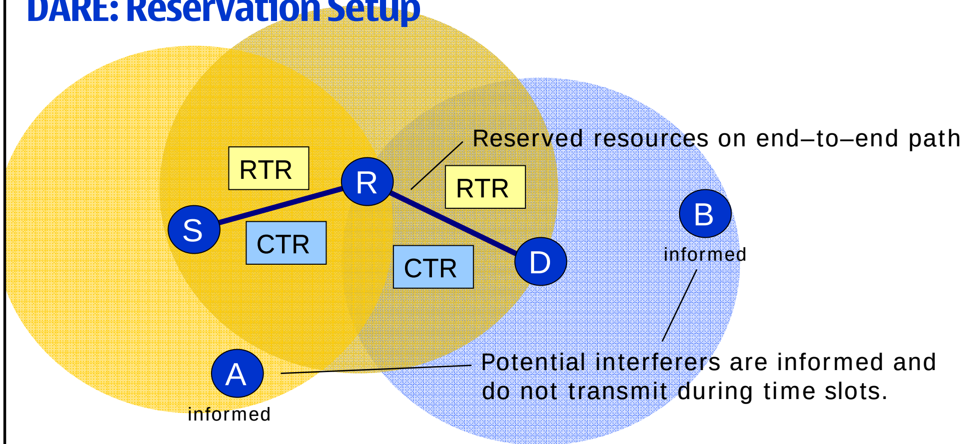
Example

DARE: Reservation Setup



RTR *Request-to-reserve*:
Information about requested time slot [length and periodicity]

CTR *Clear-to-reserve*

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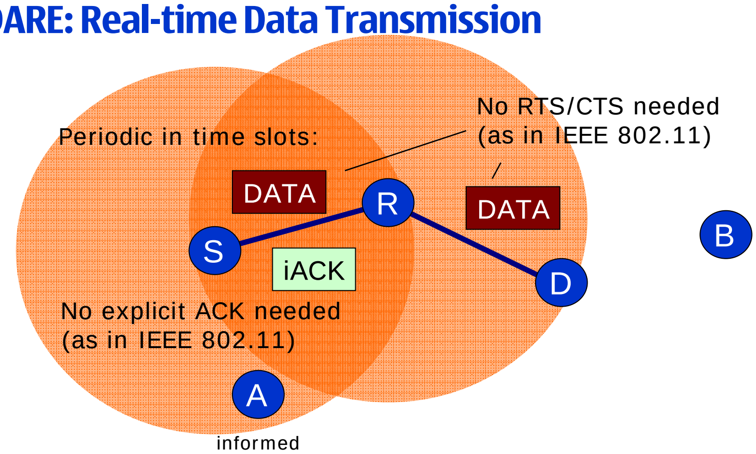
Example

DARE: Real-time Data Transmission



DATA *Real-time data* [length and periodicity]

iACK *Implicit acknowledgement* by overhearing

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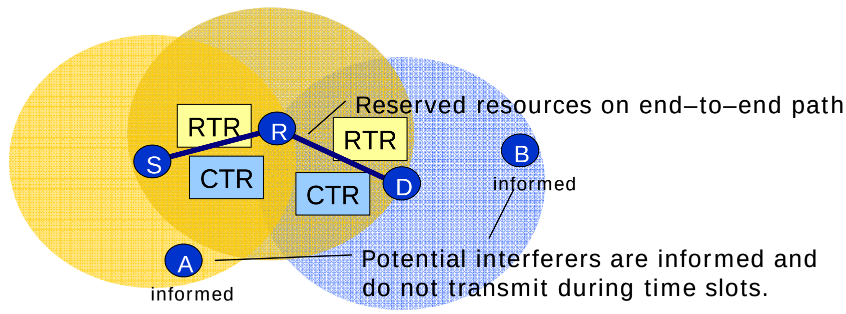
Example

DARE: Protocol Design Summary



- Locally controlled end-to-end reservations
  - Nodes on reserved path maintain (soft) reservation state
  - Need to inform vicinity about reserved slots
  - Need to agree with other reservations in vicinity – first come first serve basis
- Continously informing other nodes about reservations
  - „Biggy-packing“ of information on other messages
  - How far to spread information about reserved slots – vs reuse of time slots
  - Especially difficult in case of mobility
- No central coordination or optimization of reservations and time slots

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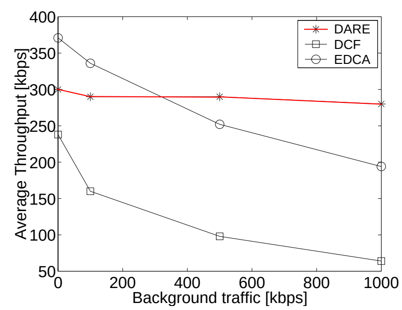
Example

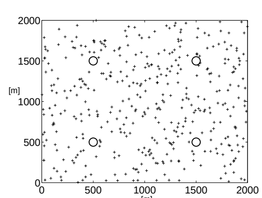
Performance Result: Dare vs EDCA (802.11 with Priorities)

- EDCA to give priority to real-time traffic
  - Retransmission timers, node queues
- DARE gives higher throughput and stable delays for higher load
  - DARE creates minimal signaling overhead

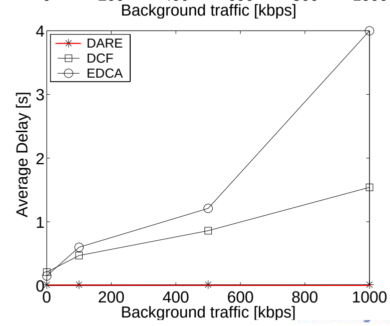


Evaluation Settings with NS2 Simulator

- 400 nodes in 2 x 2 km sqare, 230m range
- Random on-off of nodes
- IEEE 802.11 DCF and EDCA
- 10 Real-time flows with 40kb/s
- Background traffic with 20 or 50kb/s
- AODV routing protocol



Evaluation Scenario

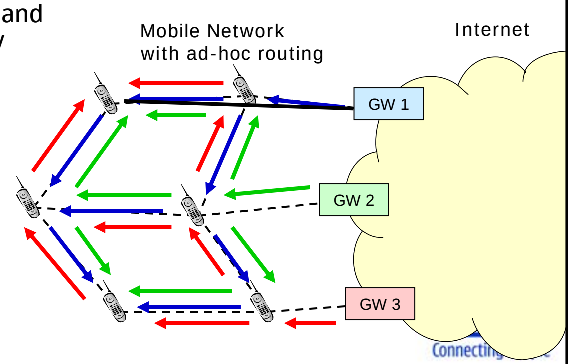


Paradigm #3: Minimise Long-lived State Information

- Reduce state which is **synchronized** between two or more nodes

Eample

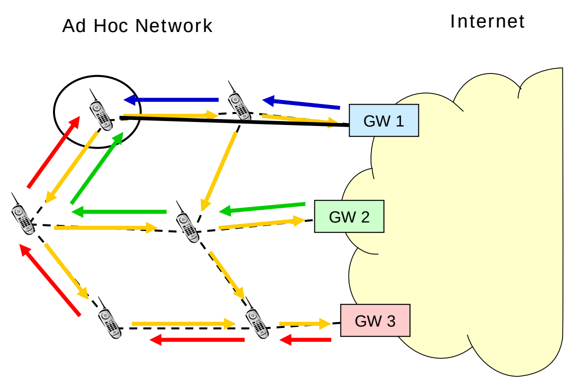
- Discovery of gateways in multi-hop access network
  - Self-organizing ad-hoc network(s) connected to Internet via gateways (GW)
  - Nodes discovery optimal gateway and obtain global internet connectivity
- Comparison of proactive and reactive discovery
- Proactive discovery
  - Gateways send periodic announcement
  - Nodes select best gateway



Example

Reactive Discovery of Gateways

- Reactive Discovery
  - Node sends announcement
  - Gateways reply
  - Nodes select best gateway
- Hybrid discovery option
  - Gateways in proactive mode
  - Nodes only proactive if gateway known



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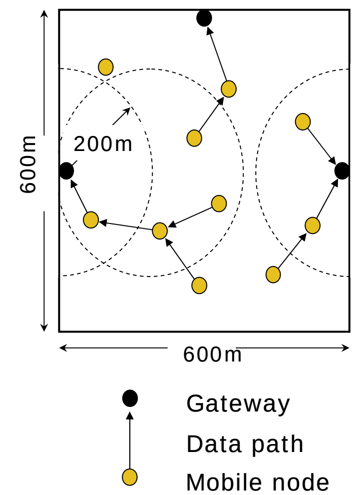
Example

Gateway Selection & Handover with Mobile Nodes

- MRAN protocol for gateway discovery/selection
  - Autoconfiguration of global address
  - Packet forwarding to/from fixed network
- Gateway selection strategies and handover
  - Proactive and reactive gateway selection
  - **Forced handovers** to gateway if old gateway lost
  - **Optimizing handovers** to closer gateway
- Testbed implementation
  - Protocol implementation in Linux
  - 13 nodes conected via WLAN
  - Mobility emulated (via packet filtering)
  - Different ad-hoc routing protocols (AODV, OLSR)



P. Hoffmann, C. Bettstetter, C. Prehofer, ***Performance Impact of Multihop Handovers in an IP-based Multihop Radio Access Network***, ACM SIGMOBILE Mobile Computing and Communications (MC2R) Review, 2006.

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draft-hofmann-autoconf-mran-00.txt

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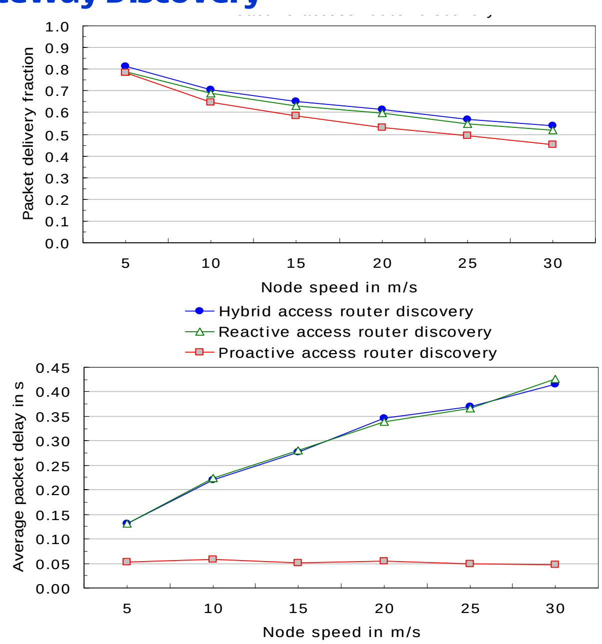
Example

Reactive vs Proactive Gateway Discovery

Evaluation Results

- Little impact on data delivery fraction
- Proactive discovery performs better for higher mobility



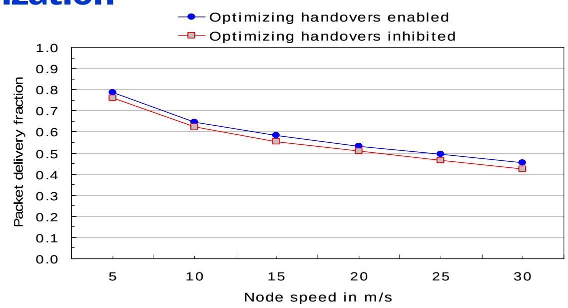
Parameters for performance evaluation

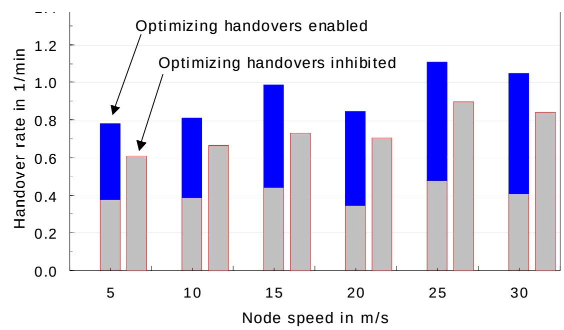
• Number of mobile nodes	10
• Number of gateways	3
• Constant bit rate of each MN	10 kbit/s
• Measurement period	30 min
• Number of experiments	10

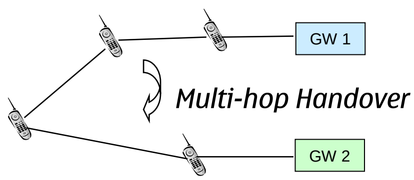
Example

Multi-hop Handover Optimization

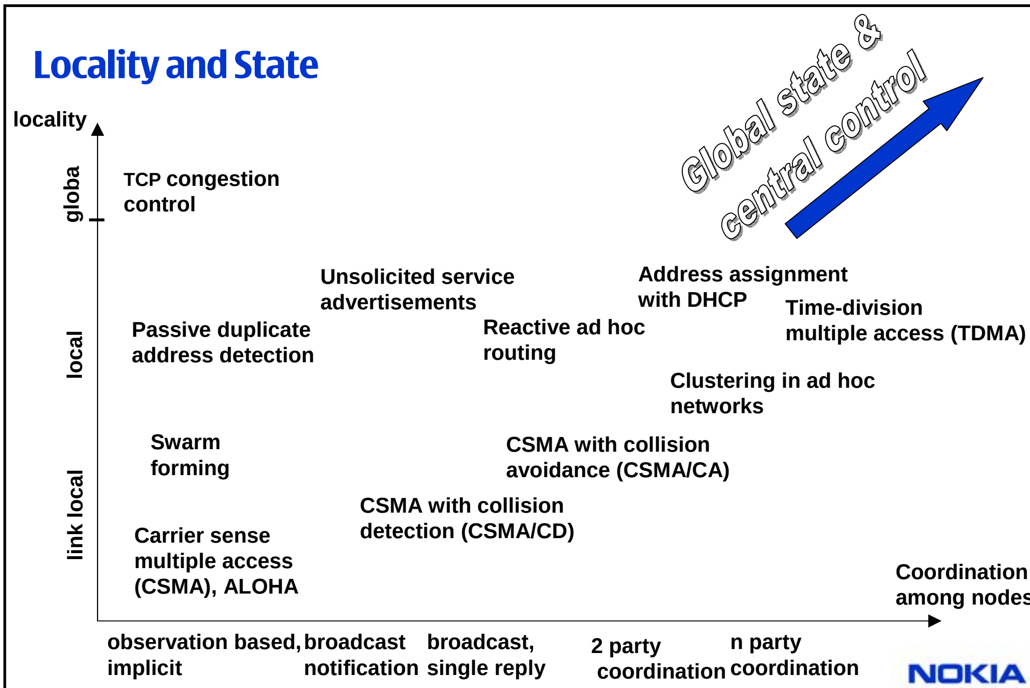
- Optimizing handovers faster than forced ones
  - Optimizing ~ 5ms
  - Forced ~ 35 ms
- Optimizing handovers increase number of handovers
- Optimizing handovers improve system performance







Locality and State



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Paradigm #4: Adaptation

„Adapt or perish, now as ever, is nature's inexorable imperative" H. G. Wells

- Need to adapt when local/implicit mechanisms do not suffice
  - Monitor and adapt – often implicit communication

Levels of Adapation

- **Level 1:** A protocol is designed so that it adatps continuously (e.g. failure, mobility)
  - Adapt parameters continously
  - E.g. TCP transmission window control adapts to round trip time (RTT)
- **Level 2:** A protocol is designed to adapt to specific events and conditions
  - Adapt parameters (e.g. value of timers, cluster size) in order to optimize system performance
  - E.g. TCP reduces sending rate upon congestion
- **Level 3:** A protocol is designed so that it realizes if the changes are so severe that the currently employed mechanism is no longer suitable
  - Major reaction and change of behavior
  - E.g. TCP time out upon consequtive packet loss

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Summary of Design Paradigms & Dependencies

What makes self-organization difficult in practice?

1. Achieve global properties with local behavior
   - E.g. resource control, addressing
   - Local control
2. Do not aim for perfect coordination
   - Permit local inconsistencies if detectable or tolerable
   - Implicit coordination (by detecting inconsistencies)
3. Minimize long-lived state
   - E.g. discovery instead of fixed bindings
4. Adaptation
   - Detect when employed mechanisms are at their limit

Implies

Enables

Uses

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Example

From Networking to Pervasive Computing & Services

How to design pervasive applications?

- Where to maintain state information?
- What level of control can we get?
- How to adapt to changing environment?
  - Robustness is key
- Hope to cope with heterogeneous environment?
  - Devices, protocols, radio
  - E.g. short range of RFID tags

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Example

Example: Opportunistic data collection

- Can we use the same principles for pervasive computing?

Local book finder example:

- All books in a building have RFID tags
- Phones in the building record books in vicinity
- Phones exchange data when people move
  - Optimized data storage and data exchange with network coding
  - Requests can be sent to local devices, e.g. “Find a Java book close by”

Elena Fasolo, Christian Prehofer, Michele Rossi, Qing Wei, Jörg Widmer, Andrea Zanella and Michele Zorzi, ***Challenges and New Approaches for Efficient Data Gathering and Dissemination in Pervasive Wireless Networks***, Intersense 2006

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Summary and Outlook

Design principles of self-organization

- Identification of main paradigms of self-organized networks
- Self-organization leads to new research approaches and system design
- Towards „design patterns“ and methodology for self-organized systems

Related trends & opportunities

- Context-aware pervasive systems
  - How to manage context information?
- Web services & service oriented architecture for pervasive systems
  - Stateless services and „document-oriented computing“
- Self-organized security mechanisms
  - Bio-insprired anti-body generation for mal-ware detection