Organic Algorithms for Complex Networks

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Outline

- Project introduction
- Basic Organic Principles
  - Role assignment/role changing, flocking
- Utilization of Organic Principles
  - Organic Clustering
  - Emergence of regularity by local rules
- Current work
- Conclusion and outlook

Project Introduction (1)

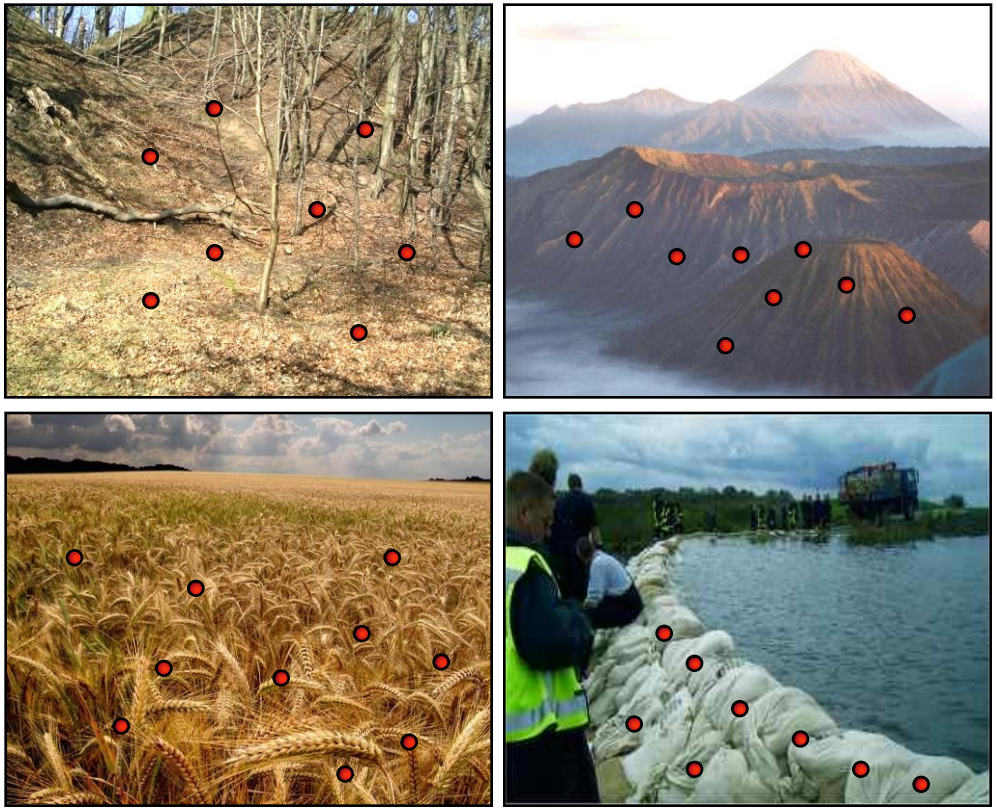
Sensor network = paradigm of a complex network

Scenario – Environment observation:

- Forest fire surveillance
- Detection of volcanic activity
- Precision farming
- Flood protection

Task:

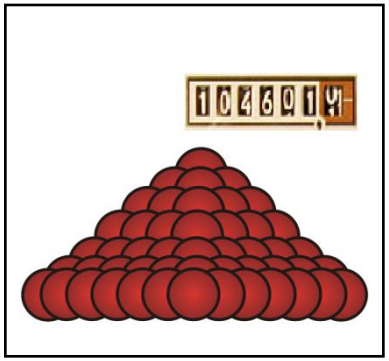
- Collect sensor data at many locations
- Transmit collected data to sink

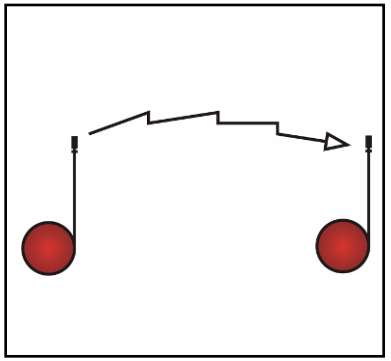


Project Introduction (2)

Network Properties:

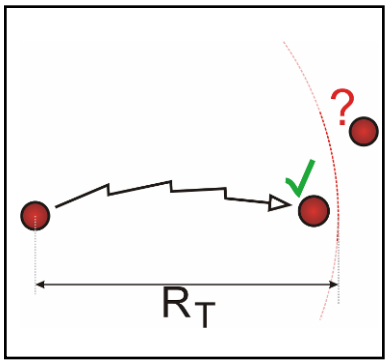
- High node count
- Random distribution
- Wireless communication

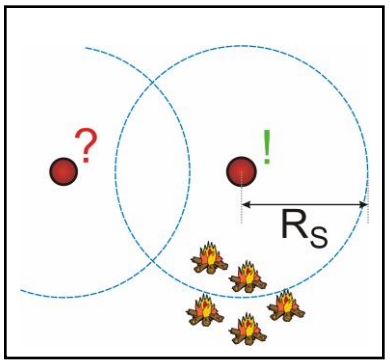




Node Properties:

- Limited transmission range
- Limited sensing range
- Limited resources





Project Overview

Typical Problems:

- Limited energy
- Missing global information
- Dynamic events impact network structure

- Centralized control infeasible
- Self-organization required
- Energy awareness required

Overall goal:
Increase lifetime and robustness of sensor networks by using OC

Phase 1:

Research of applicable OC principles for sensor networks

Research of self-organized communication

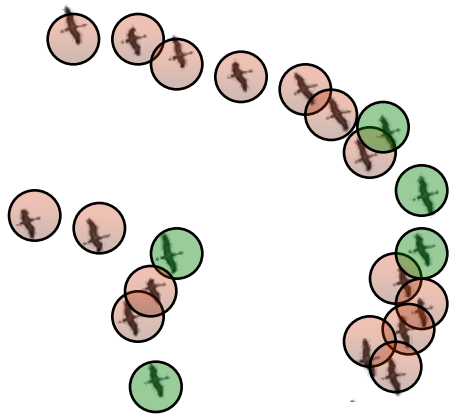
Phase 2:

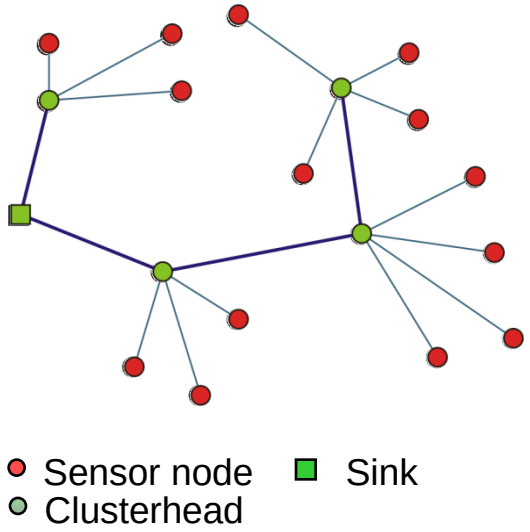
Utilization of OC principles for emergence of network structures

Utilization of OC principles to handle dynamic events

Basic OC Principles (1)

Role assignment / Role changing – Introduction





Role assignment

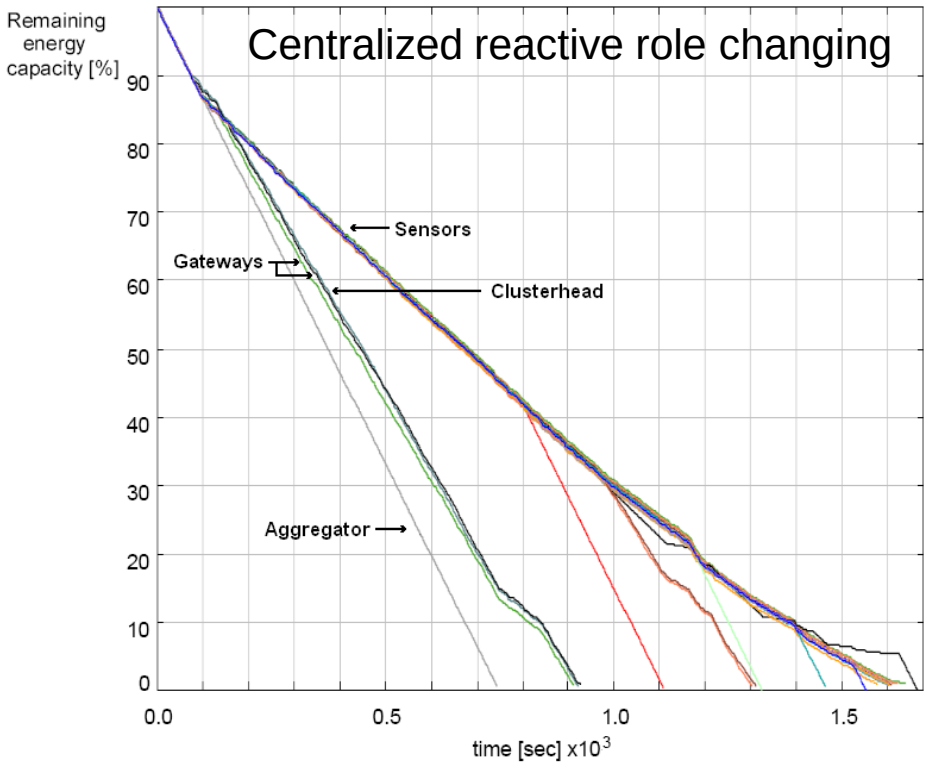
- Specialization
- Hierarchy

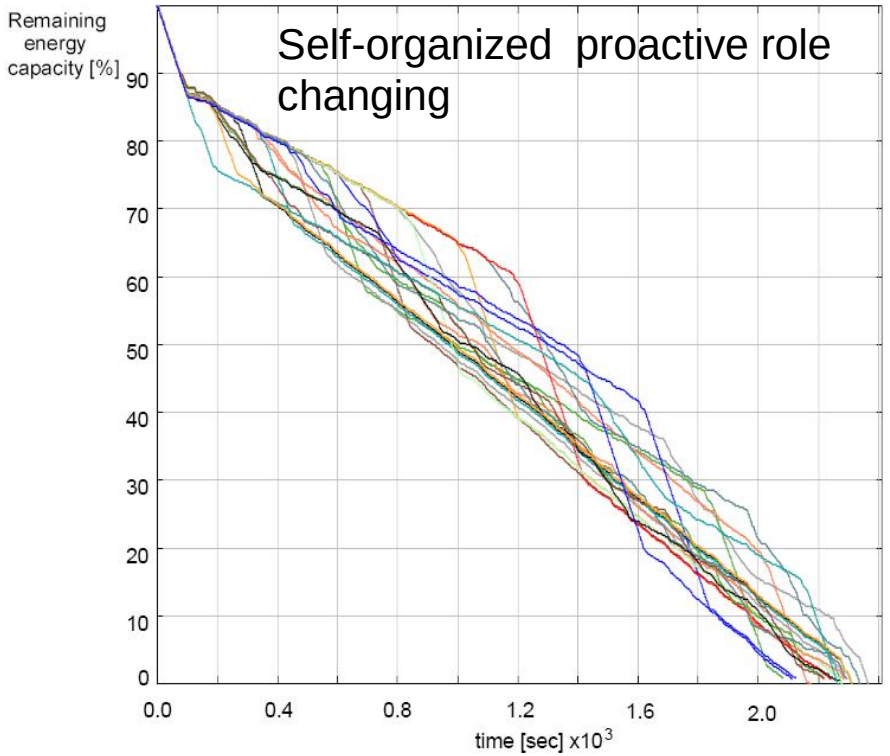
Role changing

- Energy balance
- Increase of lifetime

Basic OC Principles (2)

Role assignment / Role changing – Application [Rei 06]





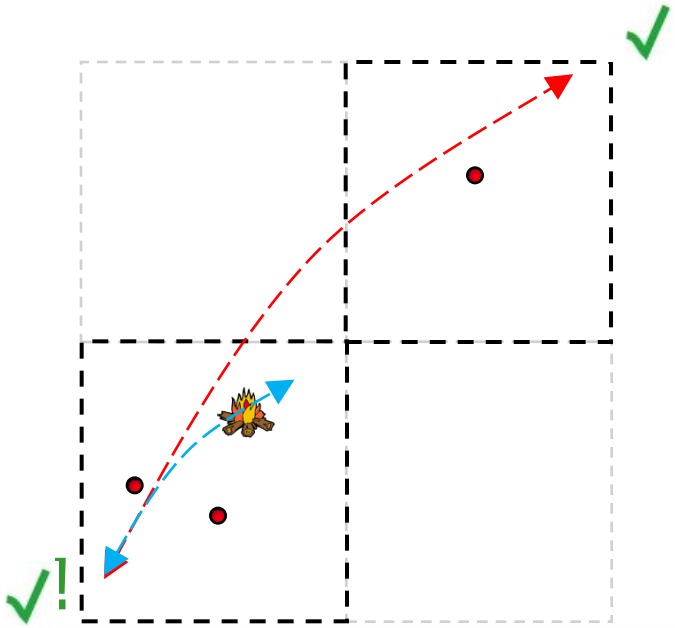
Self organized role changing ► Lifetime extension by 40%

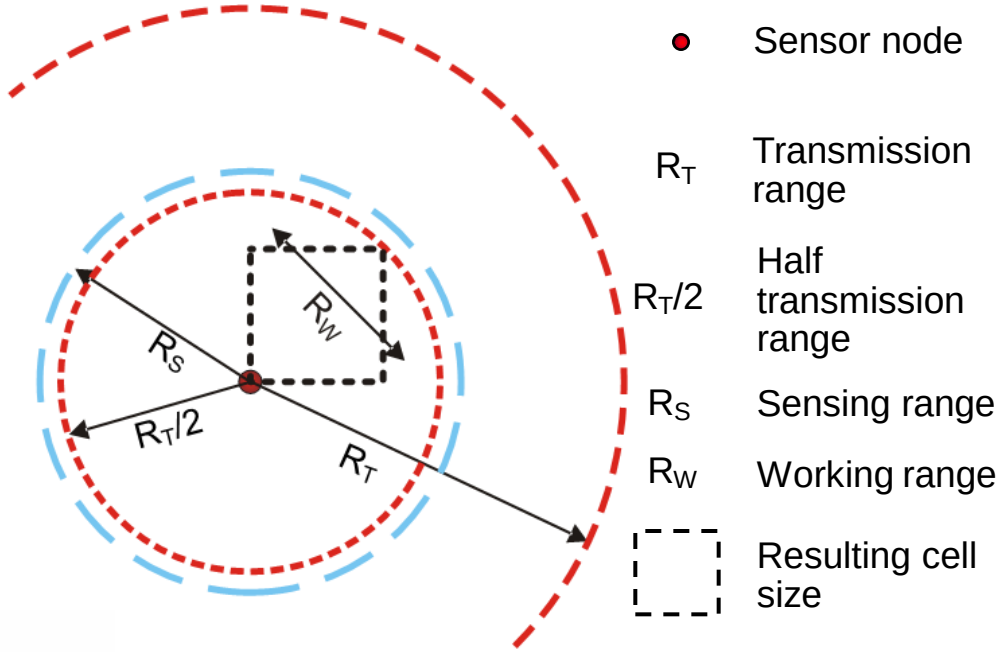
Limit: Nodes have to be exchangeable — Hence, we need geographical ”Flocking”

Basic OC Principles (3)

Geographical Flocking – XGAF [Sal07a]

- Split the observing area into cells, each defines a cluster
- Clusters organized by self-organized role changing protocol
- Cell size depends on sensing and transmission range
- Introduction of working range R_W, $R_W = \min(R_S;R_T/2)$
- Maximum cell dimension equal to R_W





*XGAF = Extended geographical adaptive fidelity

Basic OC Principles (4)

Geographical Flocking – XGAF

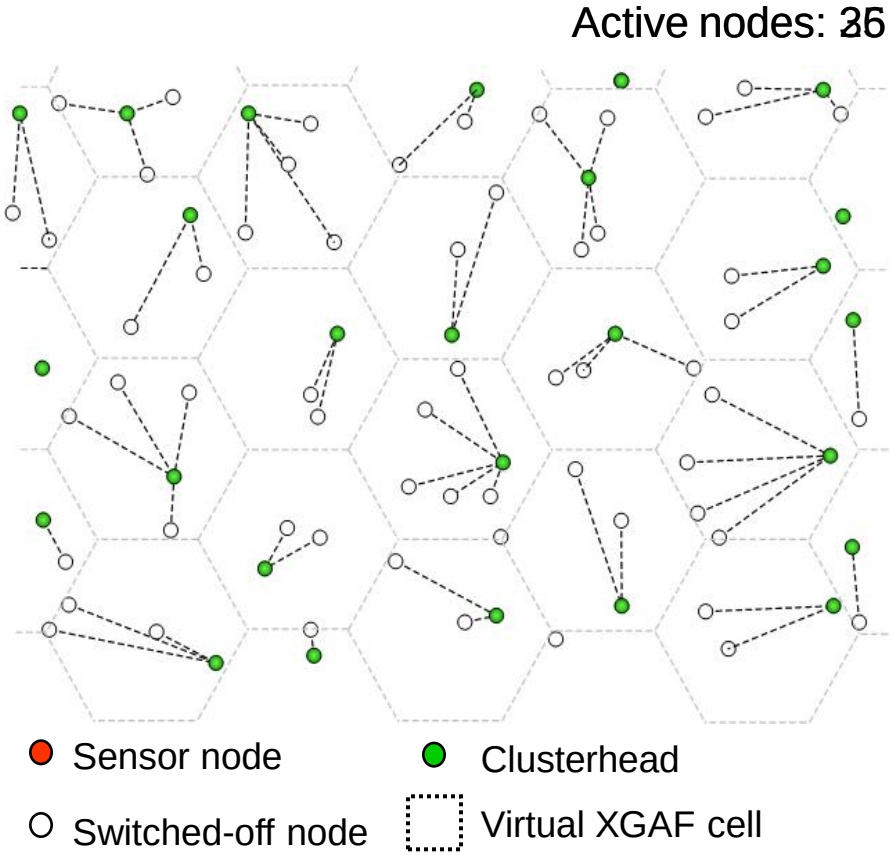
- Subdivision into cells
- Cluster emergence in each cell
- Possibility to save energy by switching-off all nodes but one per cell
- Hexagonal cells achieve even better results [Sal07b]

Limitation of localization-based cellforms:

- *Global* information necessary

Challenge:

- Migration from localization-based to localization-free clustering

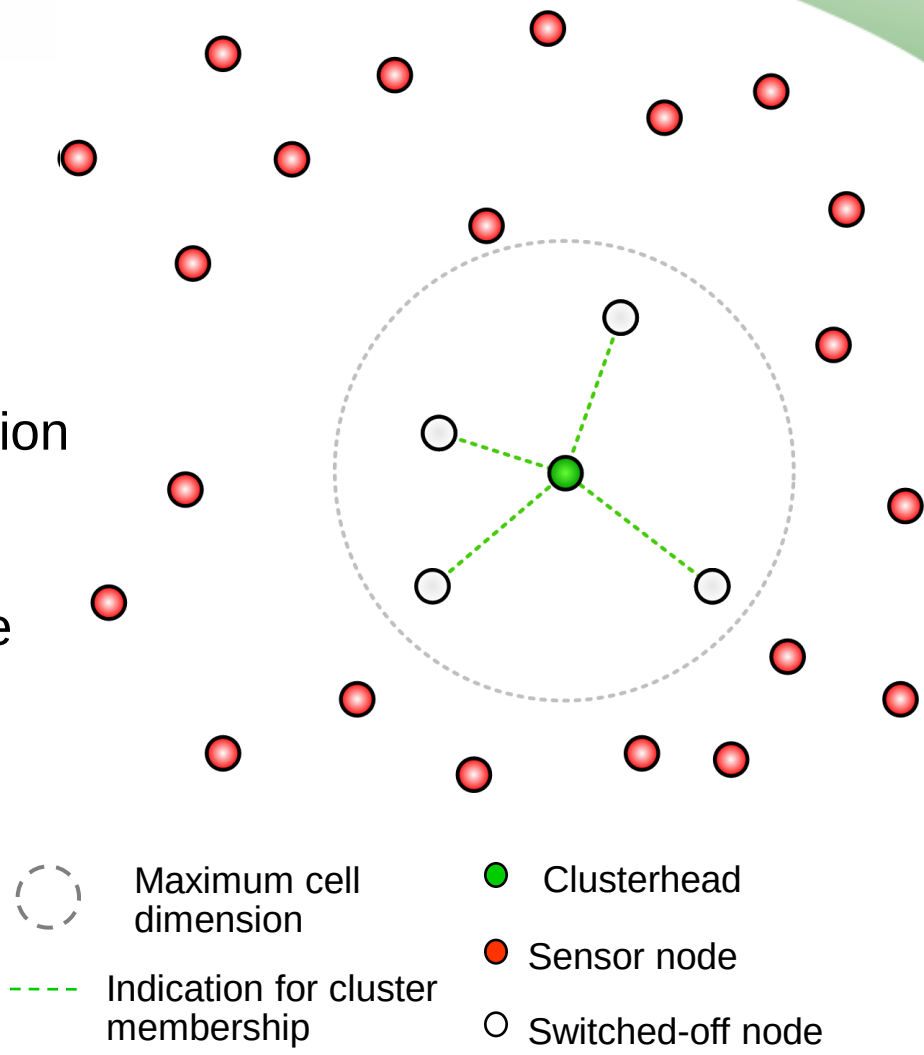


Organic Clustering (1) – First Approach [Sal08a]

- Approximate the XGAF cell with a circle
- Clusterhead sends broadcast message using adapted transmission range of $R_W/2$
- Recipients of this message join the cluster

Challenge:

- Choice of further clusterheads



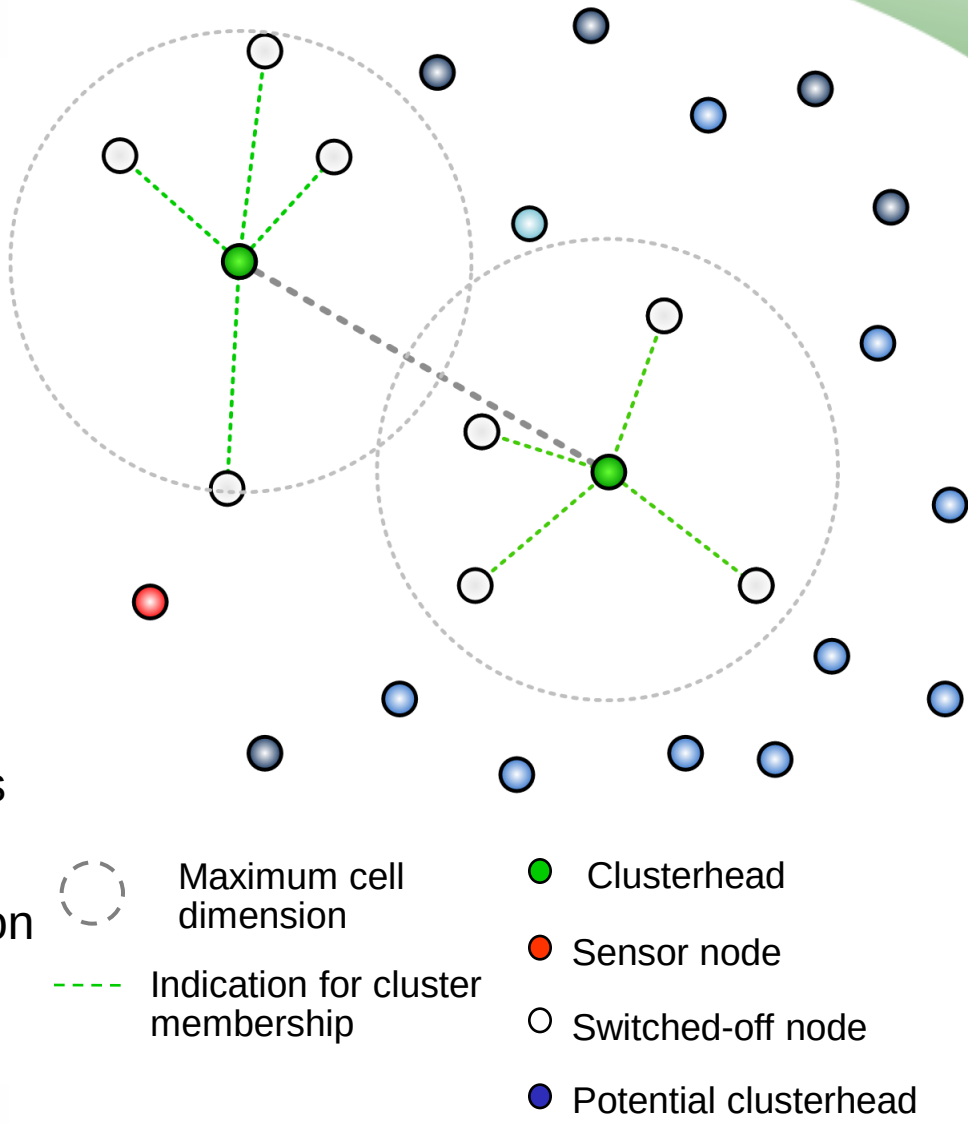
Organic Clustering (2) – First Approach [Sal08a]

- Send second broadcast message, Range R_W
- Recipients become potential clusterheads
- Distant nodes are more feasible to become clusterheads for an optimal clustering

How to approximate nodes' "fitness"?

- Utilize answer messages of joined nodes
- Each received messages decreases fitness value
- Choice of new clusterheads based on their fitness

Each clusterhead repeats algorithm



Organic Clustering (3) – Drawbacks

Challenge I:

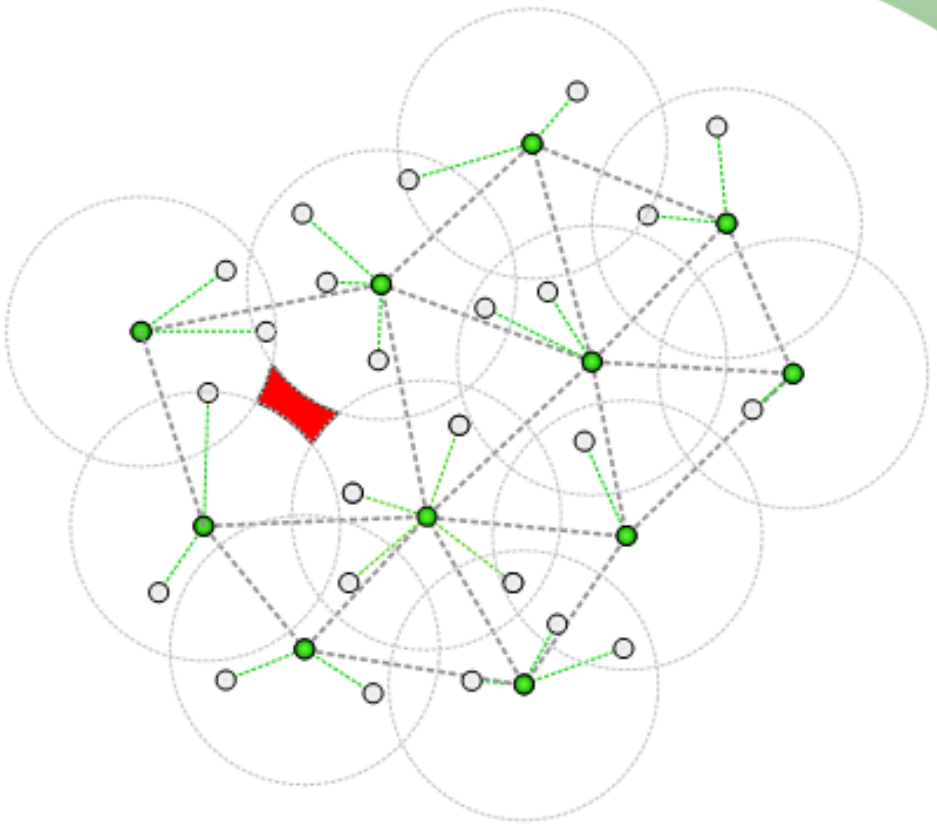
- Network holes in spite of optimal cluster choice

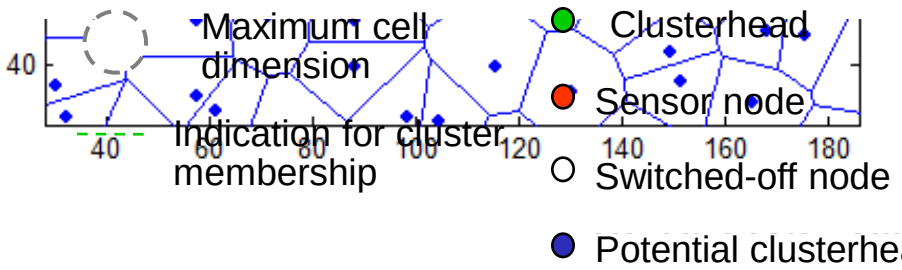
Challenge II:

- No convergence to regular structures

Challenge III:

- “Wild growth” of cluster structure may lead to network holes





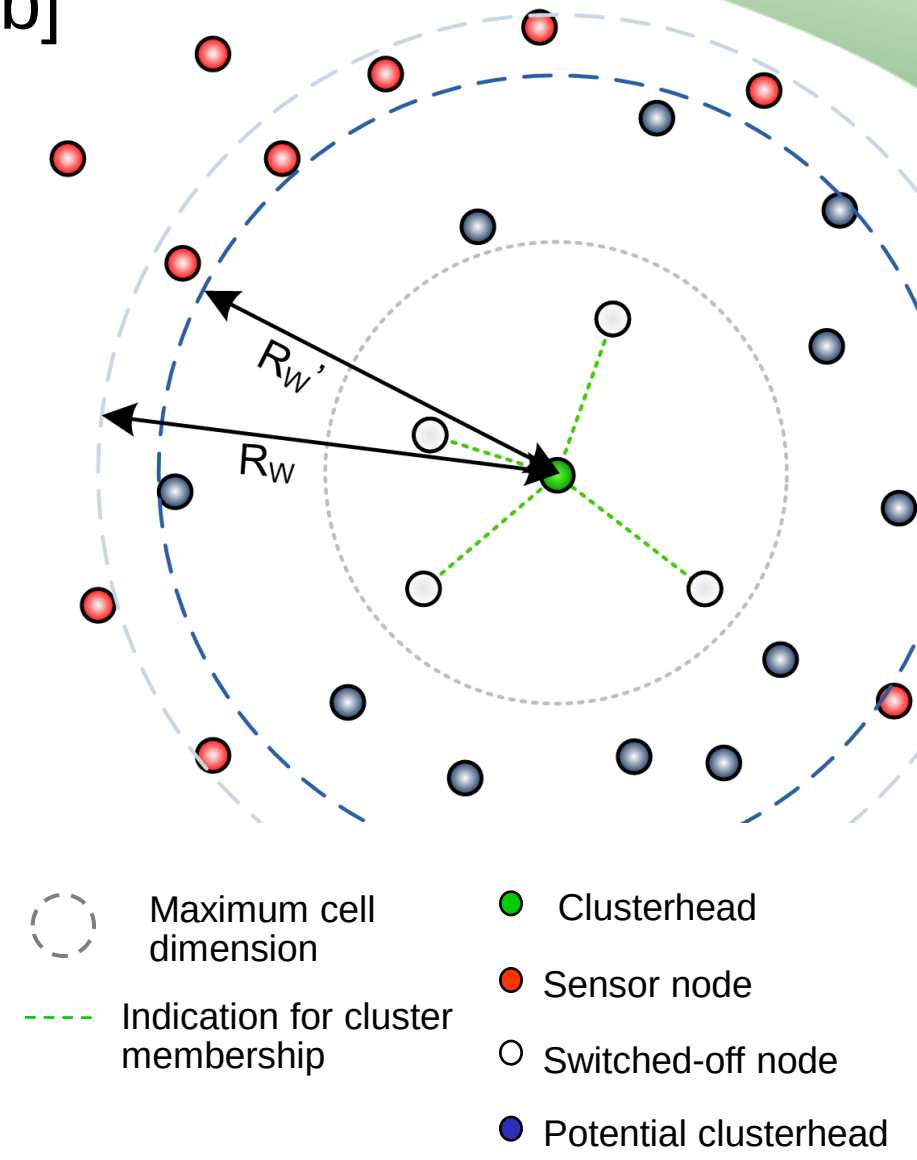
Organic Clustering (4) – Advanced Approach [Sal08b]

Challenge I:

- First approach may lead to network holes in spite of optimal cluster choice

Solution:

- Refinement of clusterhead selection
- Reduction of transmission range for second broadcast message
- $R_W' = 0.5 * \sqrt{3} * R_W$



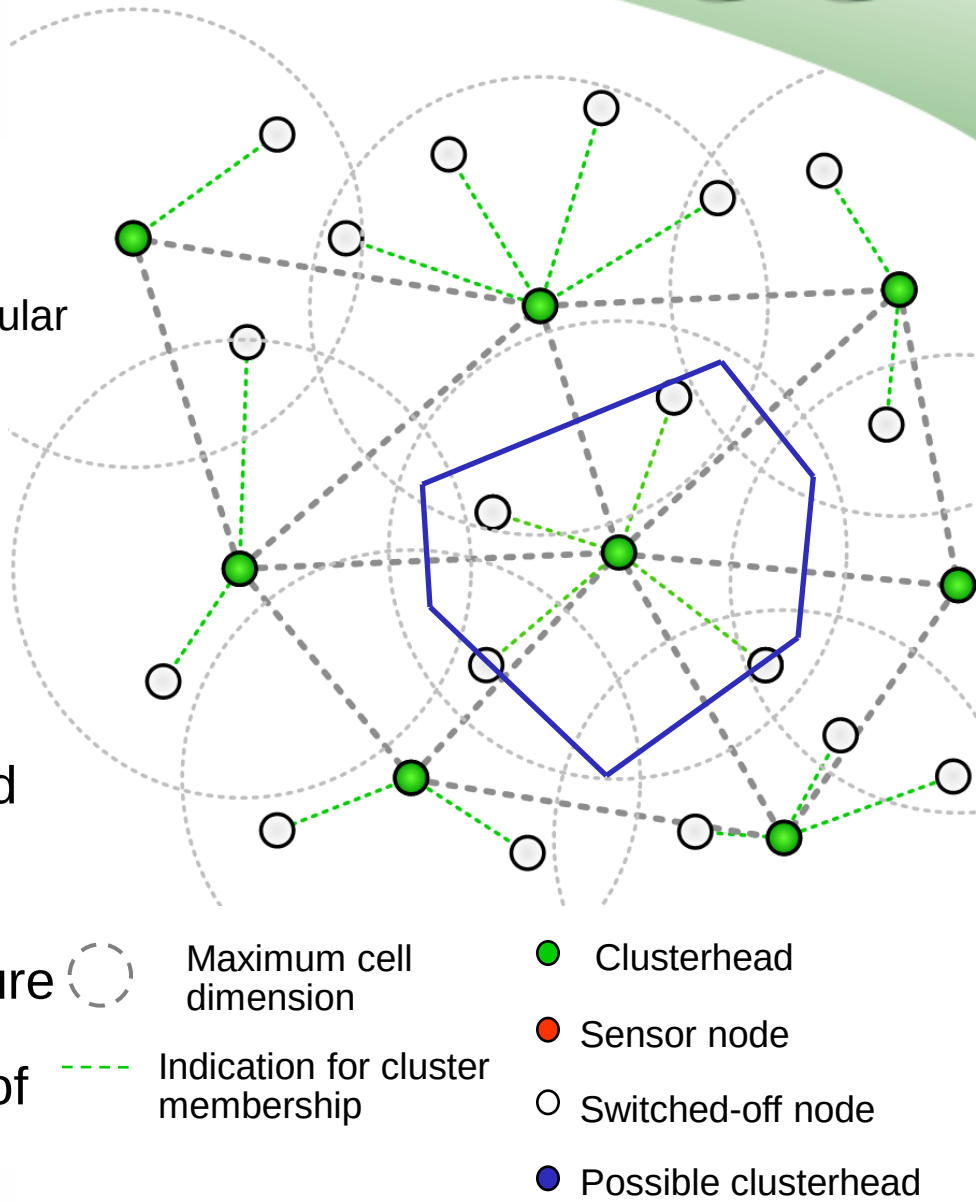
Organic Clustering (5) – Advanced Approach

Challenge II

- First approach does not converge to regular structures

Solution:

- Start with two clusterheads
- Only recipients of at least two broadcast messages are allowed to become clusterhead
- Emergence of hexagonal structure
- Regularity depends on number of deployed nodes

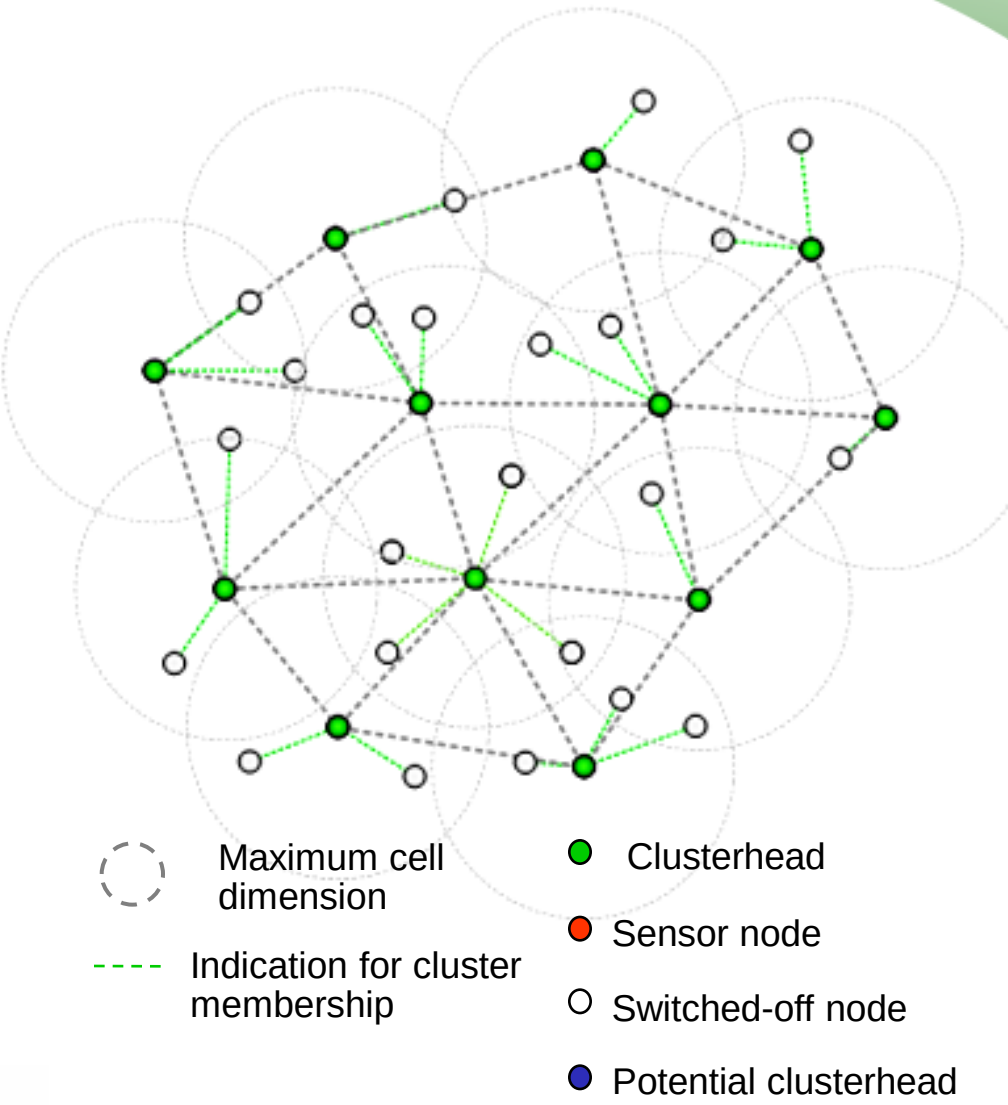


Organic Clustering (6) – Advanced Approach

- Challenge III:
- "Wild growth" of cluster structure may lead to network holes

Solution

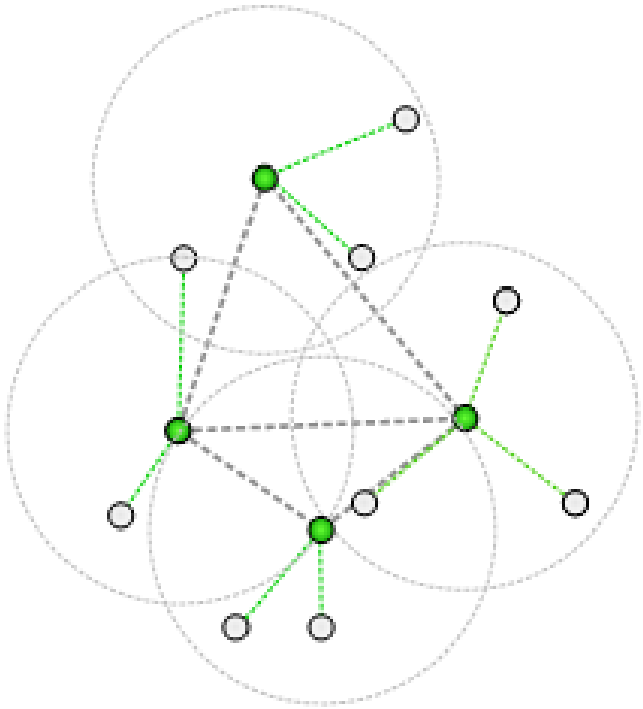
- Recipients of more than two broadcast messages boost their fitness value
- Nodes with more adjacent clusters become clusterhead earlier
- Uniform growth



Organic Clustering(7) – Advanced Approach

Further Improvements

- Cross coupling as indication for too dense clusters
- Avoidance of cross couplings leads to better cluster distribution

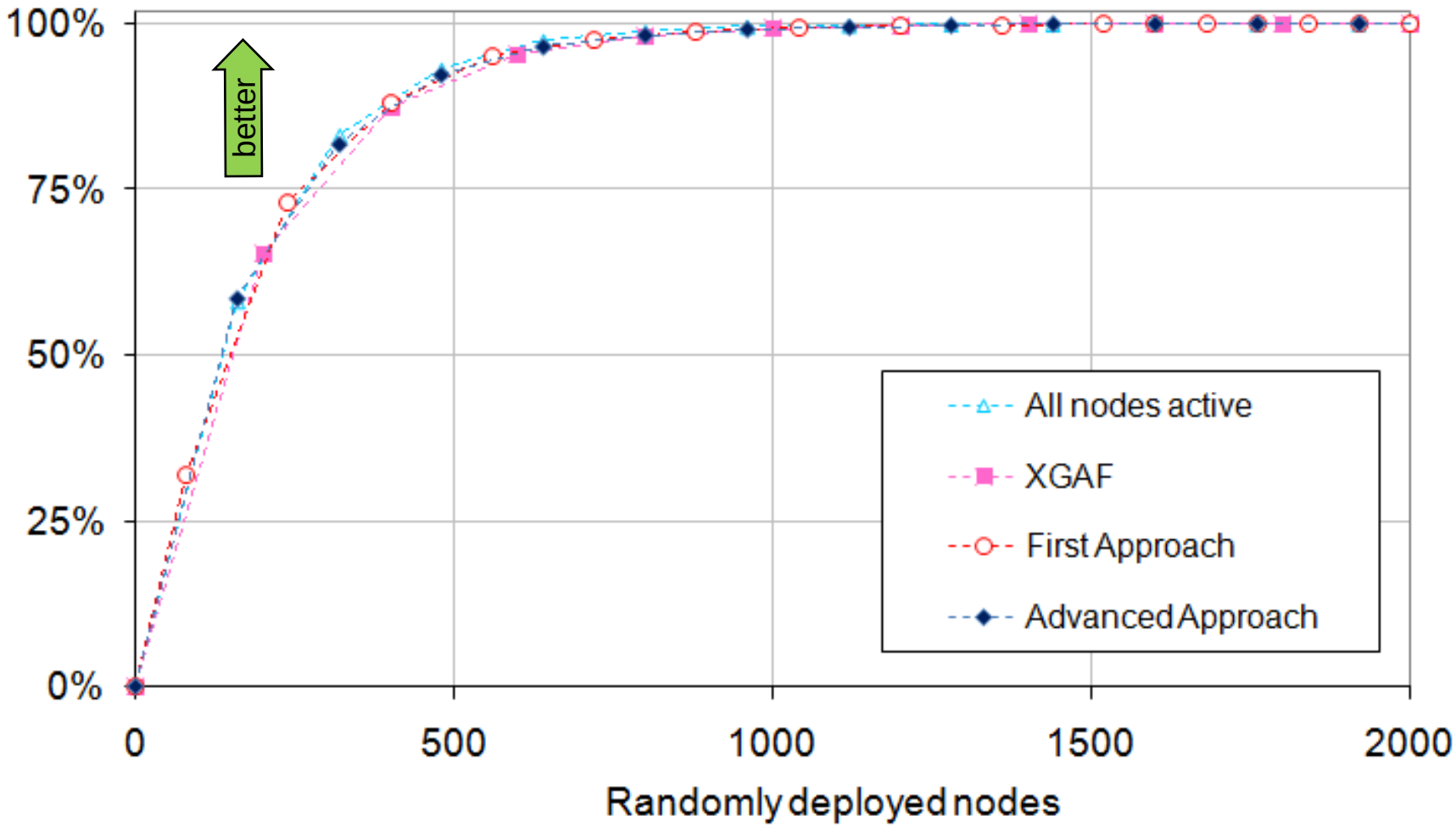


Organic Clustering(7)

Example Video

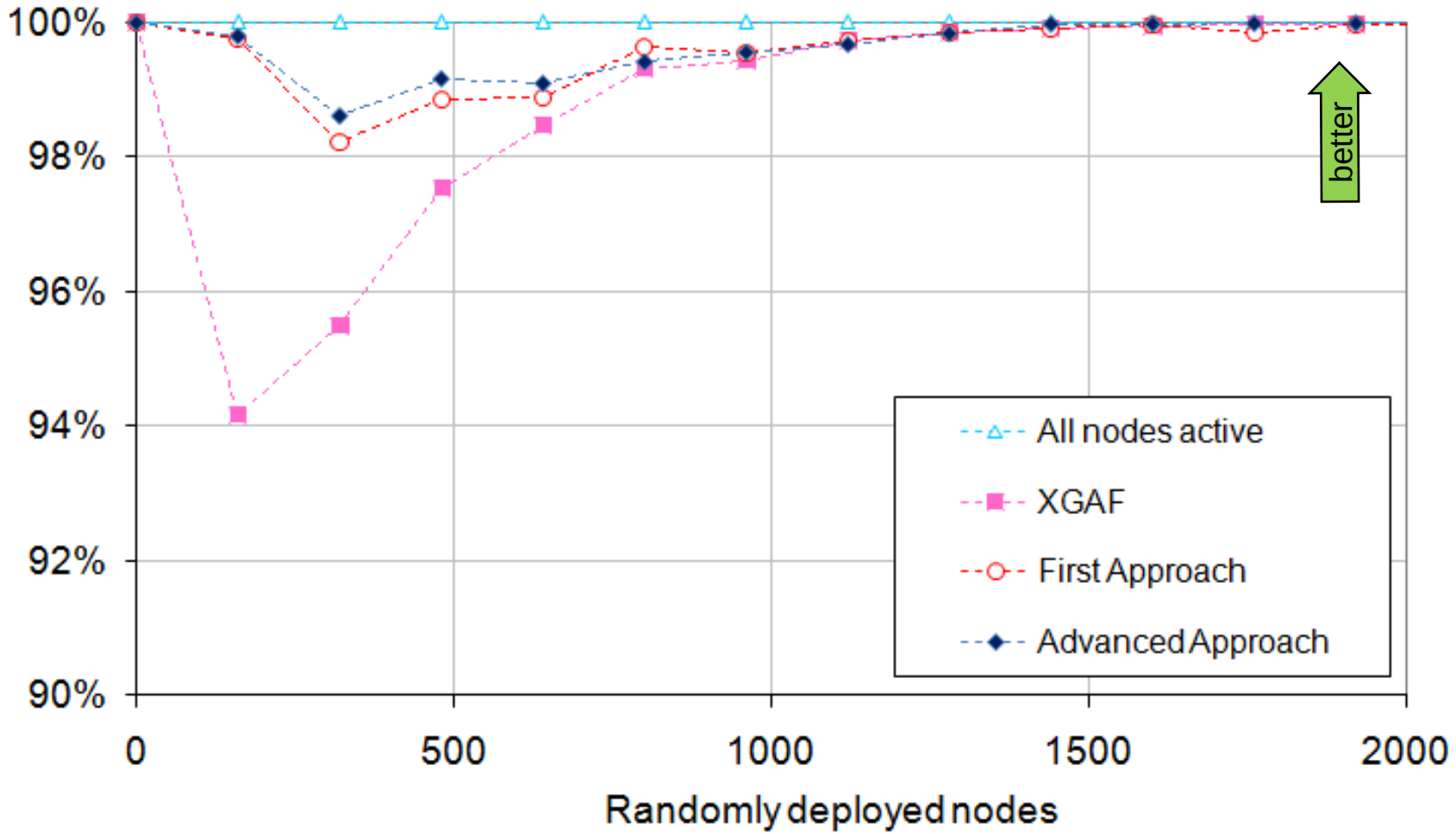
Evaluation of our algorithms

Network functionality



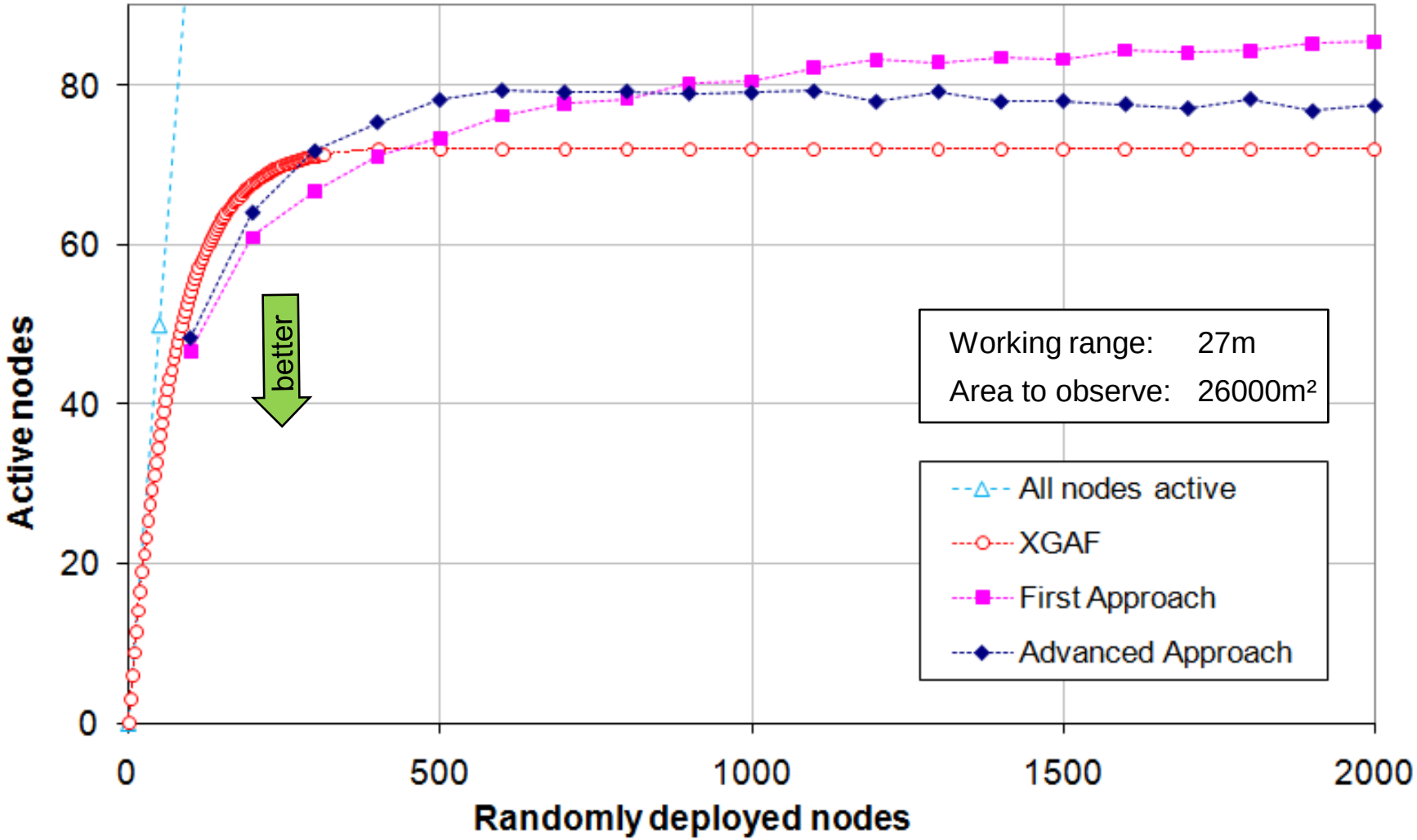
Evaluation of our algorithms

Maximum achievable network functionality



Evaluation of our algorithms

Active nodes



Evaluation of our algorithms

Further comparisons

Properties of developed algorithms	All nodes active / Simple redundancy detection approach [Tia02]	XGAF	Organic Clustering – First approach	Organic Clustering – Advanced Approach
Cluster based approach	No	Yes	Yes	Yes
Localization free	No	No	Yes	Yes
Regularity	No	Yes	No	Yes
Adaptable to our „Scale free routing structure“ [Sal07a]	No	Yes	Yes	Yes
Adaptable to our „Cell based healing“ [Sal07c]	No	Yes	No	Yes

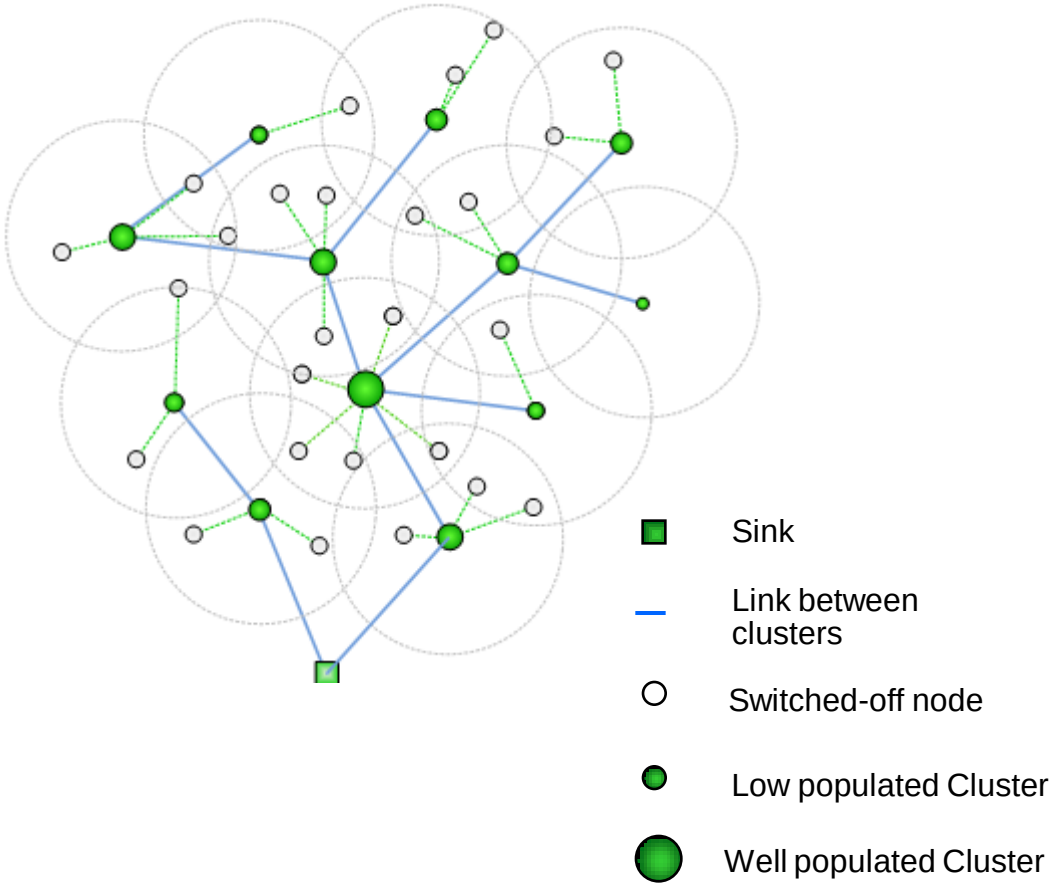
Current Work

- Improve network operation by using

  Scale Free Networks

  Graceful Degradation

- Sketch: Clusterheads of well populated clusters become hubs
- Load balanced and robust communication



Conclusion and Outlook

- Successful geographic clustering without any global and localization information
- Lifetime boost by self-organized role changing protocol
- Independent from sink, applicable in dynamic environments
- Local rules achieve regularity and allow to adopt further cell based improvements

Phase 3:
Towards reality

Challenges:
Realistic channel models
Traffic collisions

Utilities:
RSSI values
Spatial correlations

Researched methodologies from other OC-projects
(Learning Classifier Tables, Quantitative Emergence)

Questions ?

- Publications:

[Tia02] D. Tian, N.D. Georganas, “A Coverage-Preserving Node Scheduling Scheme for Large Wireless Sensor Networks”, In proceedings of the ACM International Workshop on Wireless Sensor Networks and Applications, Atlanta, USA, 2002

[Rei06] F. Reichenbach, A. Bobek, P. Hagen, D. Timmermann: „Increasing Lifetime of Wireless Sensor Networks with Energy Aware Role-Changing“ In Proceedings of the 2nd IEEE International Workshop on Self-Managed Networks, Systems & Services (SelfMan 2006), LNCS 3996, pp. 157-170, ISBN: 978-3-540-34739-2, Dublin, Ireland, Juni 2006

[Sal07a] J. Salzmann, S. Kubisch, F. Reichenbach, D. Timmermann, "Energy and Coverage Aware Routing Algorithm in Self Organized Sensor Networks", Fourth International Conference on Networked Sensing Systems; Braunschweig, Germany, 2007

[Sal07b] Jakob Salzmann, Ralf Behnke, Dirk Timmermann: „Geographical Clustering with coarse Grained Localization“, 5th International Forum „Life Science Automation“ , USA, Oktober 2007

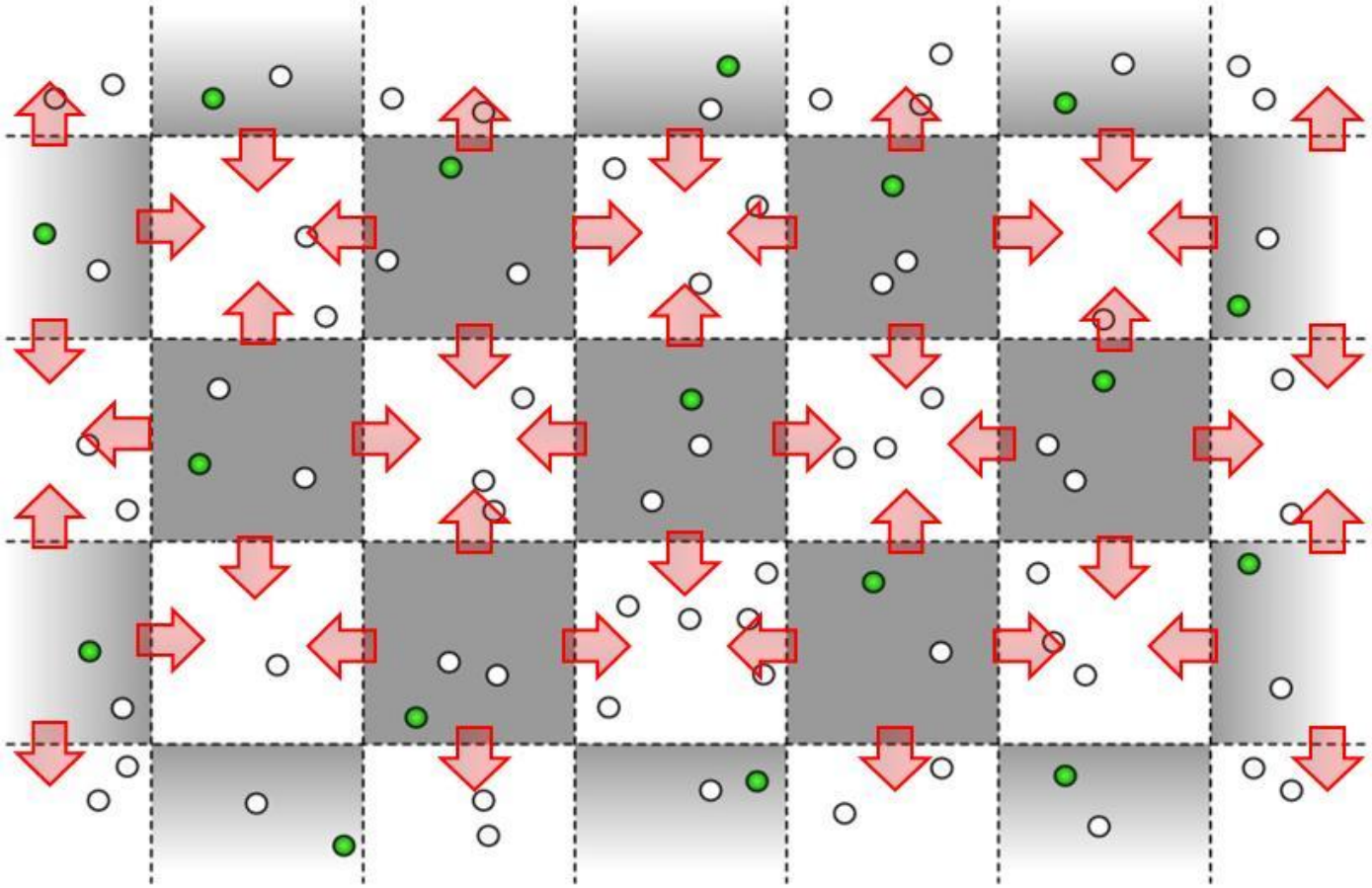
[Sal07c] Jakob Salzmann, Ralf Behnke, Dominik Lieckfeldt, Dirk Timmermann: „2-MASCLE - A coverage Aware clustering Algorithm with Self Healing Abilities“ 3th International Conference on Intelligent Sensors, Sensor Networks and Information Processing, ISBN: 1-4244-1502-0, Melbourne, Australien, Dezember 2007

[Sal08a] Jakob Salzmann, Ralf Behnke, Dirk Timmermann: „A Self-Organized Localization-Free Clustering Approach for Redundancy Exploitation in Large Wireless Sensor Networks“ GI Jahrestagung, Workshop: Adaptive und organische Systeme, München, Deutschland, September 2008

[Sal08b] Jakob Salzmann, Ralf Behnke, Dirk Timmermann: “Free-CLASH - Organic Clustering in Large Wireless Sensor Networks “, IEEE International Conference on Communications, June 2009, Dresden, *submitted*

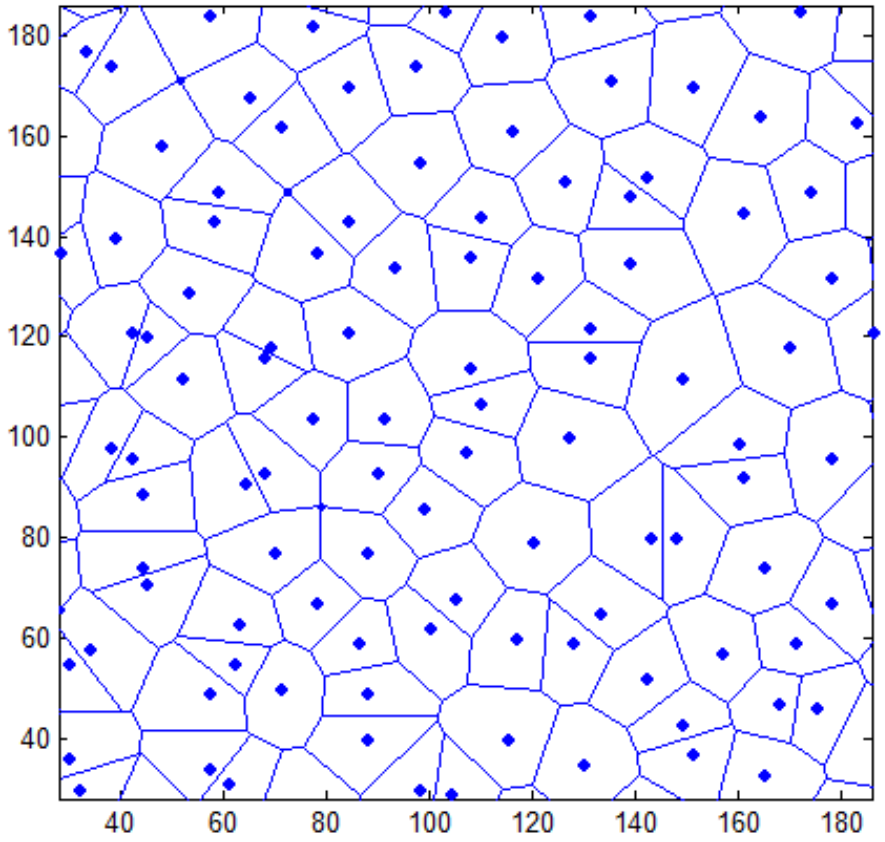
Backup

- Adoption of Cell-based healing to emerged network structures



Comparison of regularity

Organic Clustering –
First approach



Organic Clustering –
Advanced approach