Smart Teams:

Local, Distributed Strategies for Self-Organizing Robotic Exploration Teams

Presented by

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Outline

- Project Overview
- Research Themes
  - Phase I: Exploration
  - Phase I: Communications
  - Phase II: Scheduling
  - Phase II: Energy Efficiency
- Publications

Smart Teams: The Team

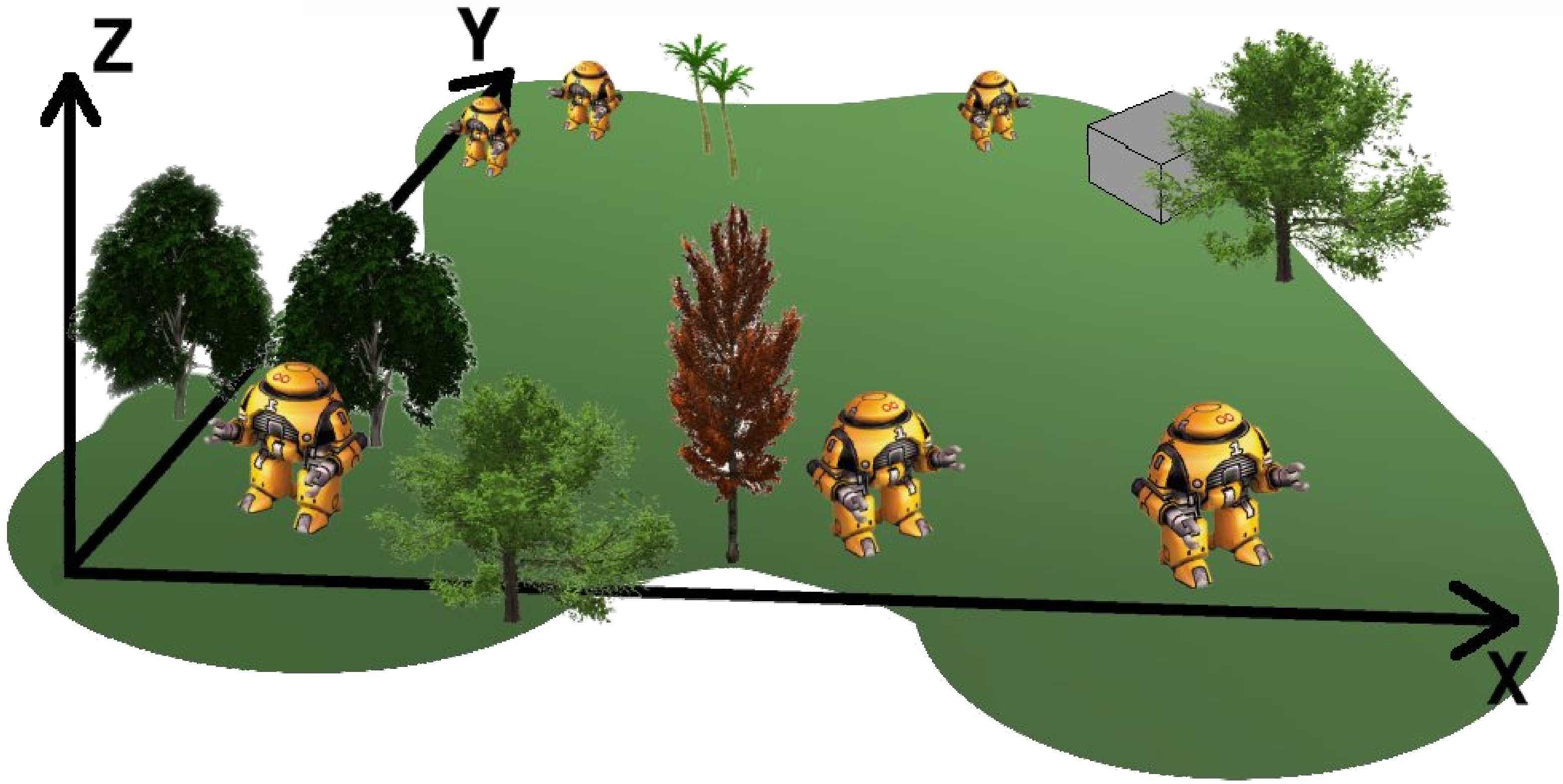
University of Paderborn

- Friedhelm Meyer auf der Heide
- Miroslaw Dynia
- Jaroslaw Kutylowski
- Bastian Degener

University of Freiburg

- Christian Schindelhauer
- Chia Ching Ooi

Smart Teams

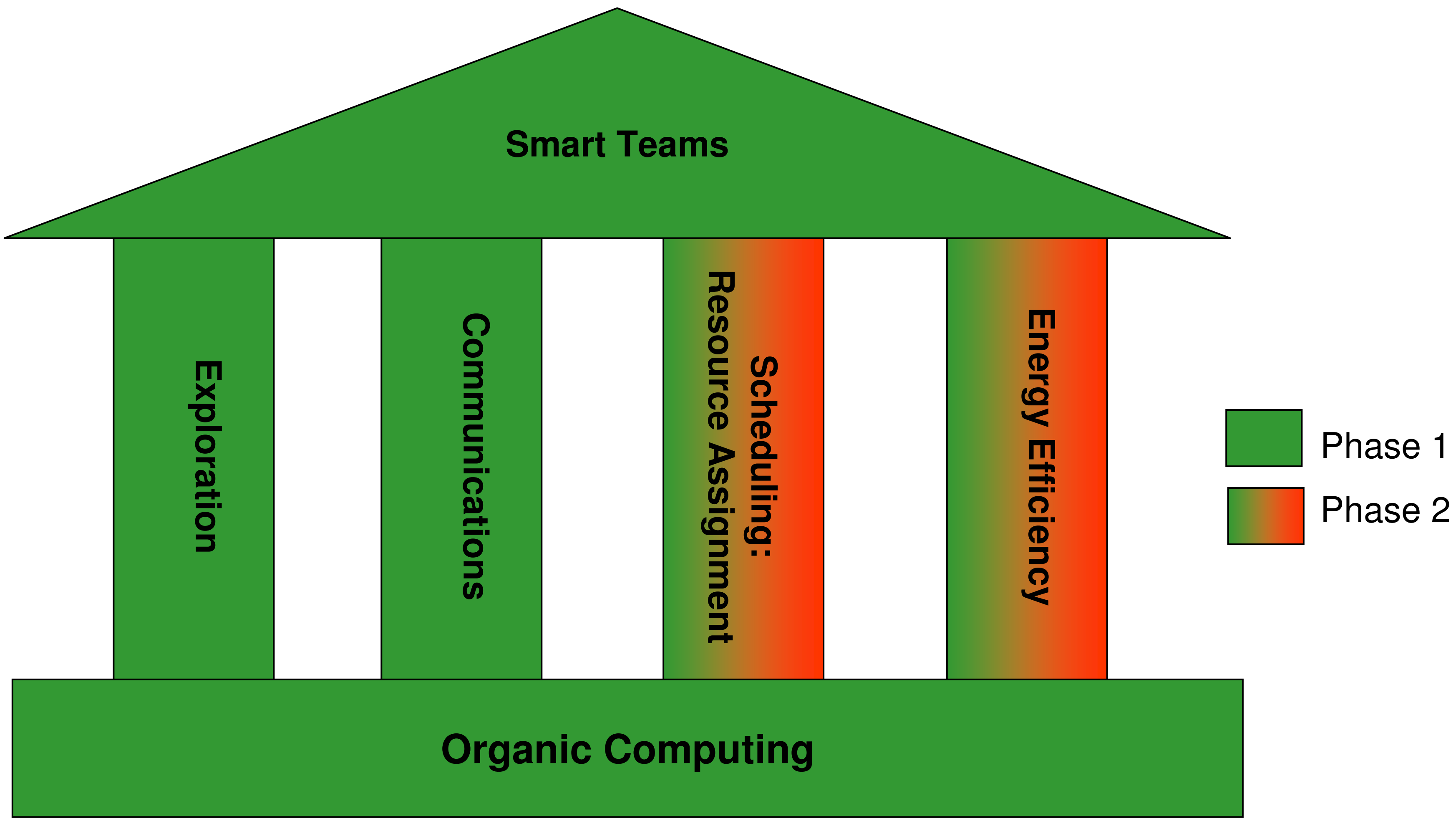


- An exploration team of self-organizing mobile robots that
  - jointly works towards a global objective based on local, distributed strategies

Intended OC Applications

- Exploration
  - Exploration of dangerous areas, e.g. sinkholes
  - Planetary or oceanic exploration
- Intelligent surveillance and monitoring system
  - Indoor surveillance, e.g. museum
  - Environmental monitoring, e.g. caves
- Search and rescue
  - Ad-hoc search and rescue team, especially the area inaccessible to human

Research Themes



Research Themes

First Phase

- ***Exploration***
  - How to explore the unknown terrain efficiently using a group of robots?
- ***Communications***
  - How to guarantee a stable communication network between robots?

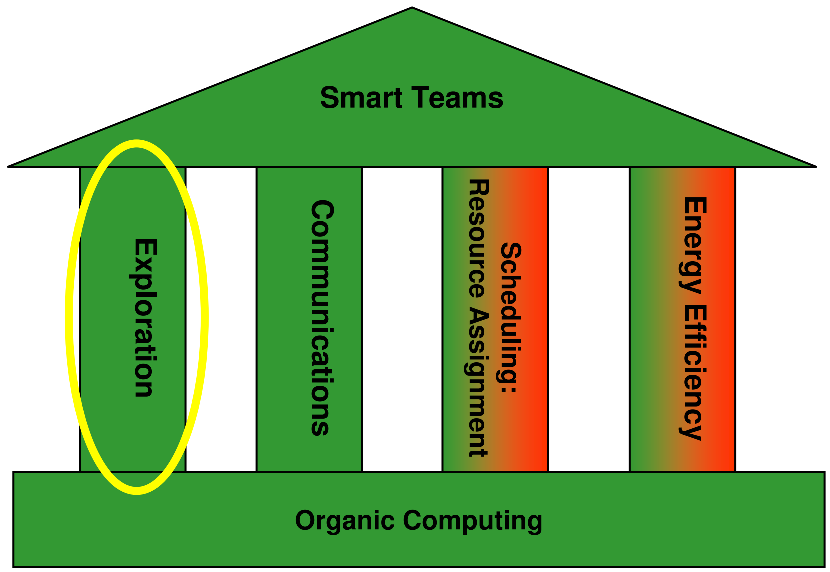
Second Phase

- ***Scheduling***
  - How to agree upon a fair resource assignment?
- ***Energy efficiency***
  - How to minimize the overall energy consumption?

Both Phases

- **Development of *SmartS simulator.***
- **Extension of *Player/Stage simulator.***

Phase I: Collective Graph Exploration



by M. Dynia

Collective Graph Exploration
Definition

- Model the environment as a graph*:*
  - nodes are locations
  - edges mean accessibility between locations (it is not necessary that all edges are traversed)
  - adjacent edges can be distinguished (e.g. by directions, IDs...)

Problem:

> *"A team of k mobile autonomous robots placed in a base $s \in V$, jointly visits all nodes of $G = (V, E)$ and finally returns to s."*

but the graph is NOT KNOWN to the algorithm in advance!!!

Online - Collective Graph Exploration
Definition

- In an online setting we assume that:
  - graph is not known to the team in advance
  - robots see only adjacent edges
  - robots can communicate within the same node
- In a step a robot can (*Look-Compute-Move*):
  - communicate with robots placed in the same node (local communication)
  - run local computations
  - traverse one edge or stay in its actual node
- Exploration cost:
  - “**energy-model**” = maximal number of edge traversals per robot
  - “**time-model**” = total exploration time
- Online analysis:
  - optimal algorithm knowing graph beforehand is more efficient
  - **competitive ratio** measures the quality of algorithms

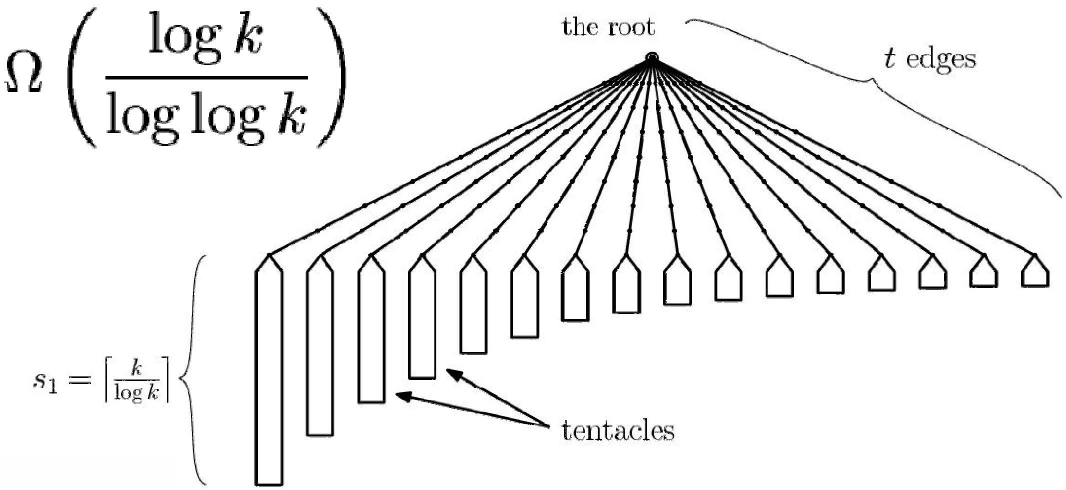
OUR RESULTS

– *Energy model*

- [arcs06] lower bound of 1.5
- [arcs06] 8-comp. algorithm for trees
- [sirocco07] improved (4-2/k)-comp. algorithm for trees

– *Time model*

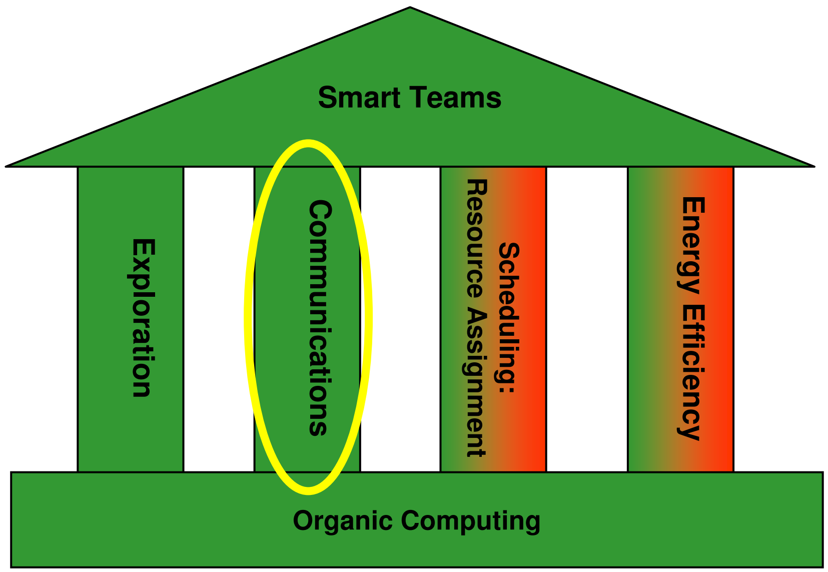
- [mfcs06] (D^1/2)-comp. for sparse trees (local comm.)
- [sirocco07] lower bound of $\Omega\left(\frac{\log k}{\log\log k}\right)$



Conclusions **and outlook**

- Maps are important in time model ...
- ... but not that important in energy-model
- In the energy model only one robot is positioned outside the base at a time. Is a parallel processing needed here at all?
- Is a local communication sufficient to explore efficiently?
- What changes for a general graph? How to explore them?

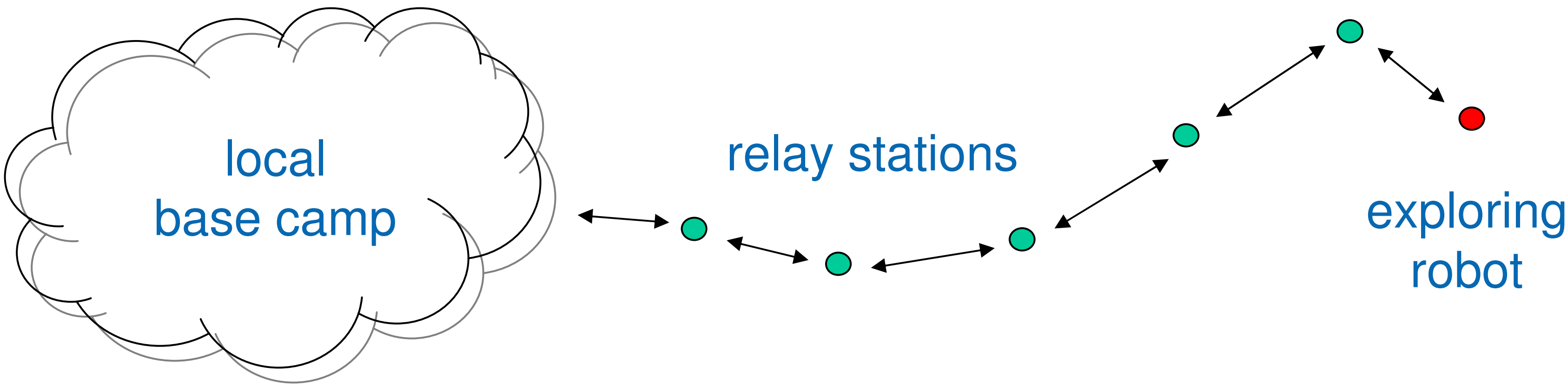
Phase I: Organising a Communication Chain



by J. Kutylowski

Organizing a Communication Chain

- Relays connecting explorer and base camp



- To develop the strategies for relays, such that the communication chain is connected and short.

Organizing a Communication Chain

- Organic strategies
  - Relay only sees current positions of its neighbors on the chain
  - Relay has no memory

⬇

- Decision on the next move is based on this limited information

Organizing a Communication Chain
Results

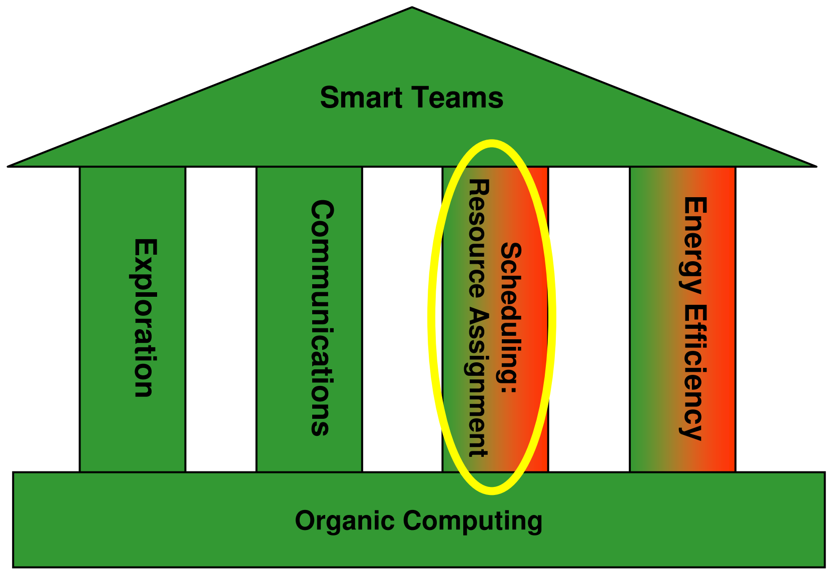
- Previous results:
  - *Go-To-The-Middle* strategy*:* very inefficient

- Current results:
  - *Hopper* strategy
    - Depends only on the neighbor positions
    - Three simple movement types
    - **Optimal performance**

Organizing a Communication Chain
Conclusion

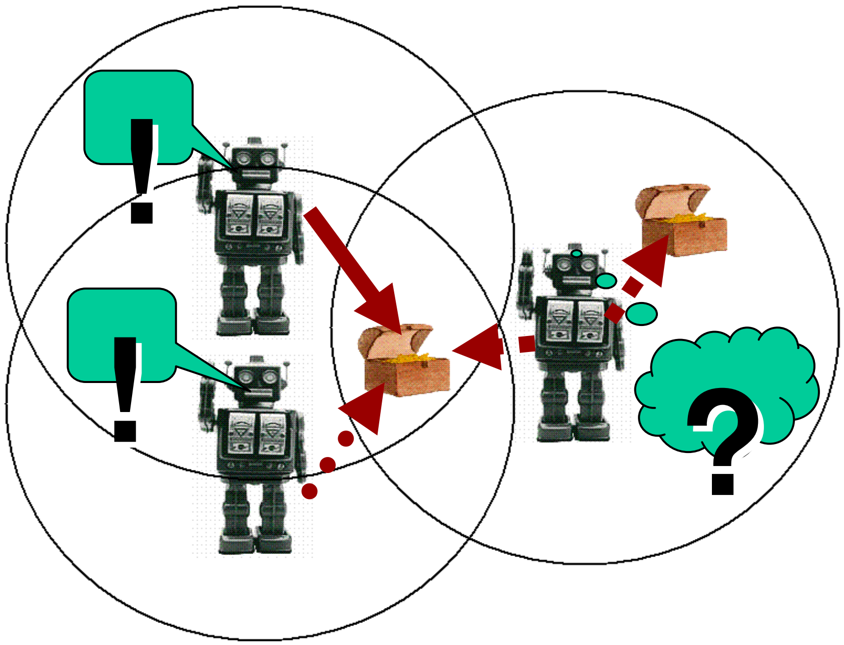
- A communication chain with small length can be maintained through *communication-by-observation* only.

Phase II: Scheduling: Resource Assignment



by B. Degener

Scheduling:
Resource Assignment



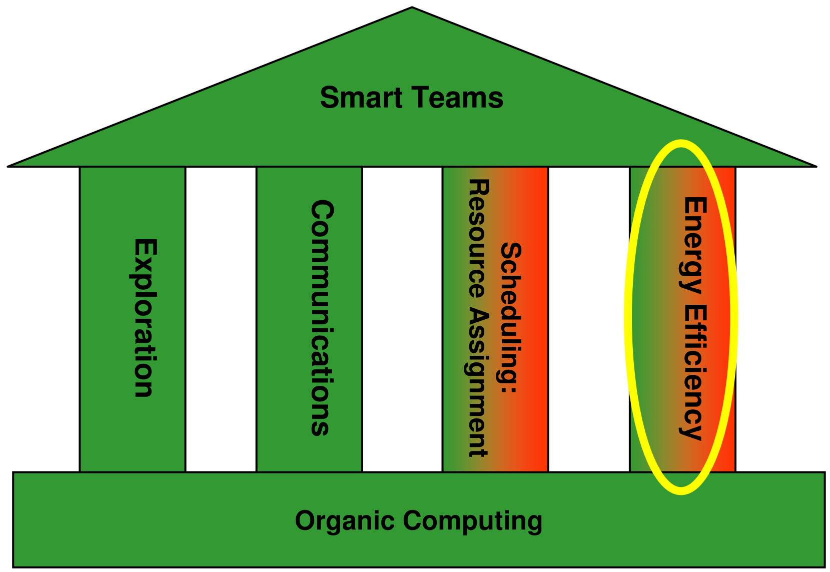
- Tasks (treasures) appearing
- Specialized robots
- Coalition formation
- Local strategies required

- Robots have special capabilities and treasures require a certain combination of them.
- Objective
  - To assign robot to cope with found treasure/different task along the exploration based on each robot capability

Scheduling:
Resource Assignment

- Main aspect: Modeling locality, dynamics and online issues properly.
- Treasures appear over time: *online problem*.
- Required local strategies for proper assignments from robot-coalitions to treasures.
- Uniform robots
  - each robot has the same single skill, and a treasure is specified by the number of robots it needs
  - *Online k-server problem*
- Heterogeneous robots
  - robots have a combination of several skills
  - each treasure needs a certain number of skills of each type

Phase II: Energy Efficiency of Networked Robots



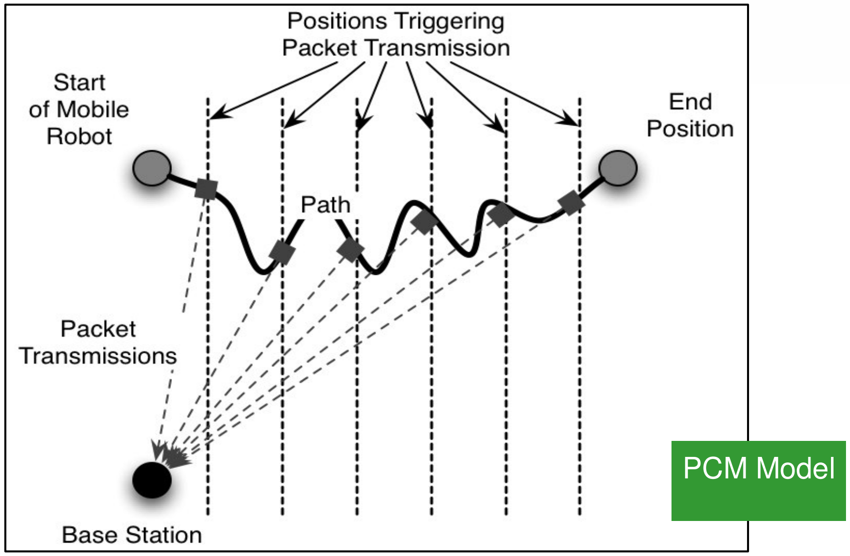
by C.C.Ooi

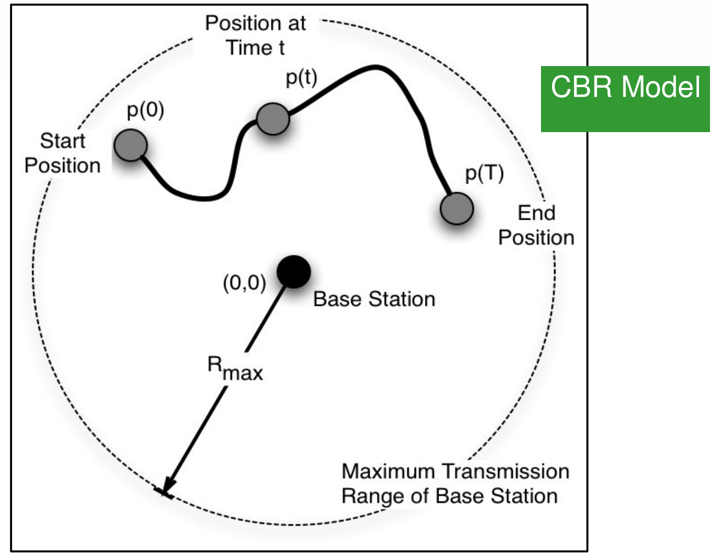
Energy Optimization

Trade-off between Communications and Mobility Cost

- Motivation
  - Limited energy resource
  - Wireless communications cost grows at least quadratically
  - Mobility cost grows linearly over distance
  - Motion power consumption is not always the highest
  - High-volume data transmission
- Goal
  - To maximize the overall lifetime of smart teams

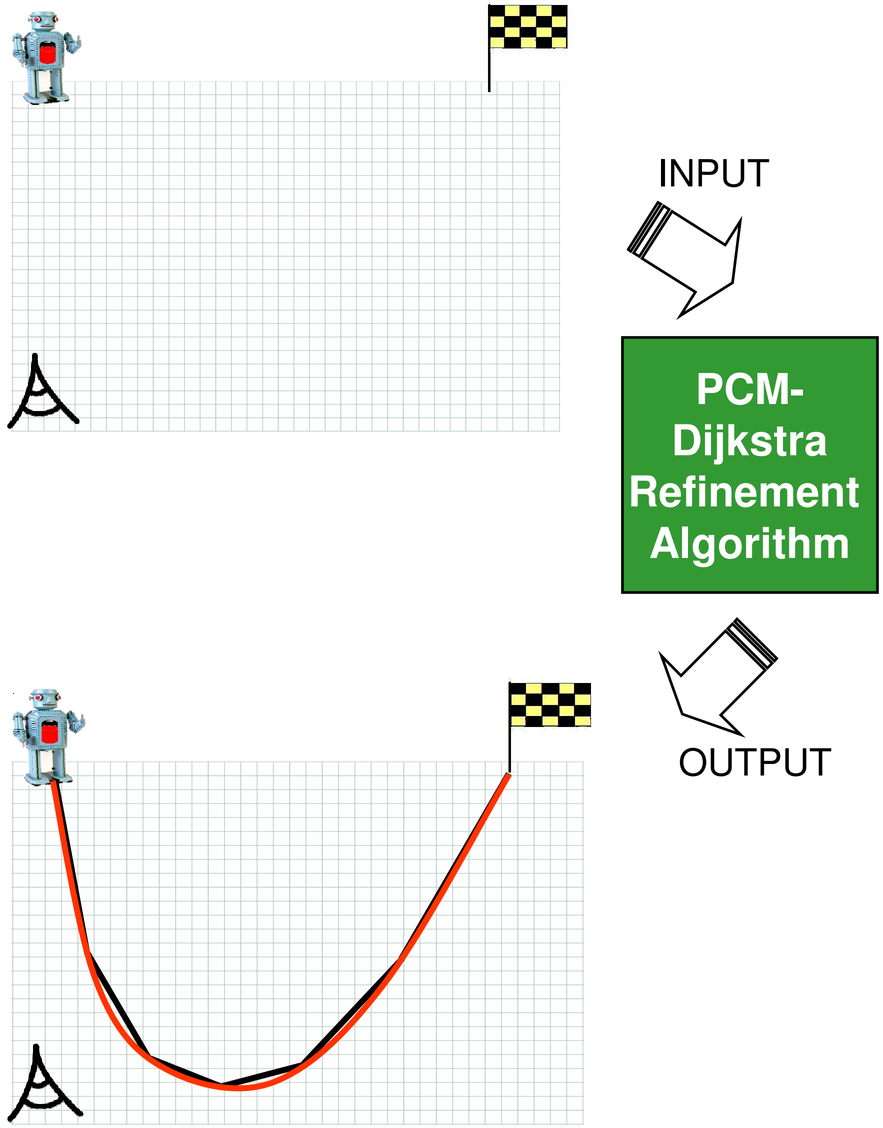
Energy Optimization
Problem Statement, Models





- Given position of BS, initial & target positions of robot, and
  - task $Q\ (A_i, N_i)$, minimize energy consumption for PCM model
  - constant bit-rate B, minimize energy usage for CBR model
- Energy Model for Mobile Robot
  - Transmission cost: $E_{tx}(n, d_c) = n \cdot (d_c^{\alpha} \cdot e_{tx} + e_{cct})$
  - Motion cost: $E_m = m \cdot d_m$
  - Total cost at point, p: $E(p) := E_{tx}(p) + E_m(p)$

Energy Optimization
Algorithm



PCM-Dijkstra-Refinement

Carefully choose algorithm parameters $c, k > 1$

$\epsilon' \leftarrow \frac{||s,g||_2}{c}$

Construct $G_{\epsilon'}$

Use Dijkstra's algorithm to compute
optimal path $p_{\epsilon'}$ in $G_{\epsilon'}$

while $\epsilon' > \epsilon$

$\epsilon' \leftarrow \epsilon' / c$

Refine around $p_{\epsilon'}$:

Construct graph $G_{\epsilon'}$

Erase all nodes in $V_{\epsilon'}$ which
are not within $k \cdot \epsilon'$ distance to a node of p

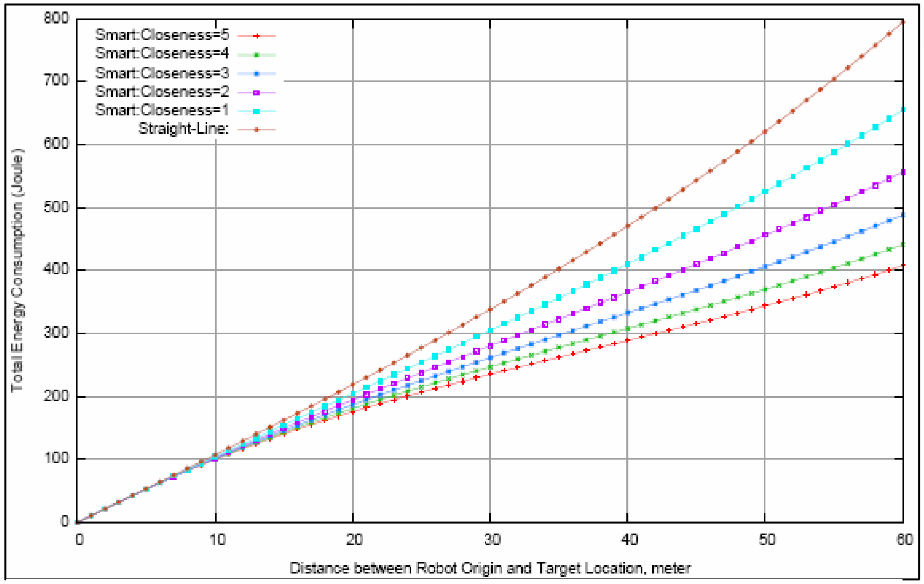
Erase all edges adjacent to erased nodes

Use Dijkstra's algorithm to compute
optimal path $p_{\epsilon'}$ in resulting graph $G_{\epsilon'}$

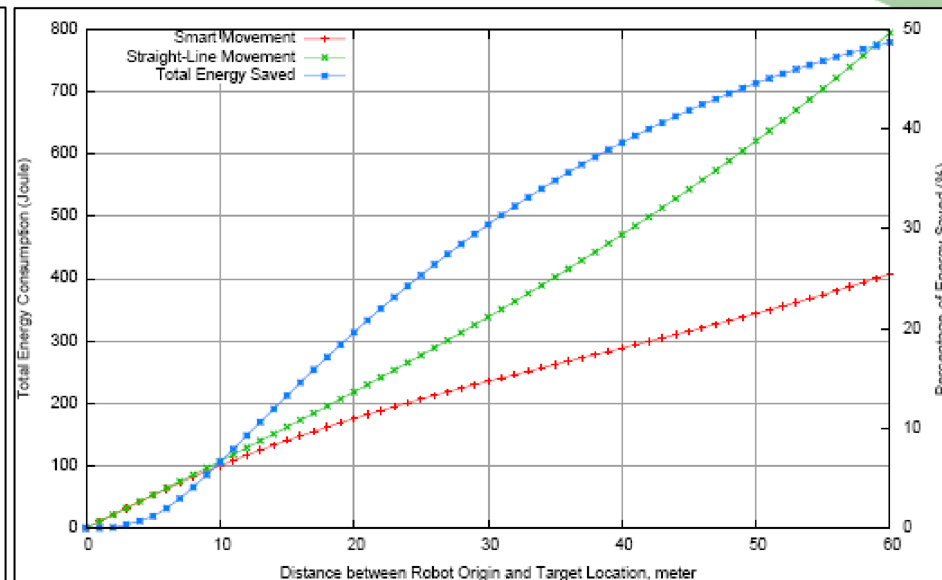
end of while

return $p_{\epsilon'}$

Energy Optimization
Preliminary Empirical Results



Distance between robot origin and base station = 85 meters



Total energy consumed and percentage saved

- Energy savings:
  - PCM: up to 48.71%
  - CBR: up to 22.18%
- Straight-line can be the optimal path if
  - Low data rate/path loss exponent
  - Short distance

Publications of Smart Teams (I)

2007

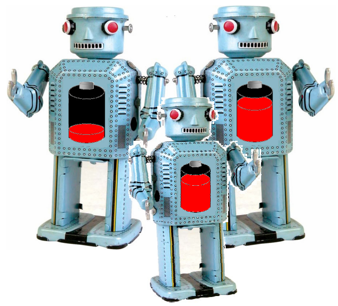
- Friedhelm Meyer auf der Heide, et. al.: **Smart Teams: Simulating Large Robotic Swarms in Vast Environments.** *(submitted)*
- Chia Ching Ooi, Christian Schindelhauer: **Minimal Energy Path Planning for Wireless Robot.** *Accepted* in International Conference of Robot Communication and Coordination (ROBOCOMM'07)
- Miroslaw Dynia, Jakub Lopuszanski, Christian Schindelhauer : **Why Robots Need Maps.** In: Proc. of the 14th Colloquium on Structural Information and Communication Complexity (SIROCCO'07)
- Miroslaw Dynia, Miroslaw Korzeniowski, Jaroslaw Kutylowski: **Competitive Maintenance of Minimum Spanning Tree in Dynamic Graphs.** In: Proc. of the 33rd International Conference on Current Trends in Theory and Practice of Computer Science (SOFSEM'07)
- Marcin Bienkowski, Jaroslaw Kutylowski: **The k-Resource Problem on Uniform and on Uniformly Decomposable Metric Spaces.** In: Proc. of the 10th Workshop on Data Structures and Algorithms (WADS'07)
- Miroslaw Dynia, Jaroslaw Kutylowski, Friedhelm Meyer auf der Heide, Jonas Schrieb: **Local Strategies for Maintaining a Chain of Relay Stations between an Explorer and a Base Station.** In: Proc. of the 19th ACM Symposium on Parallelism in Algorithms and Architectures (SPAA'07)

Publications of Smart Teams (II)

2006

- Miroslaw Dynia, Korzeniowski, Miroslaw, Christian Schindelhauer: **Power-Aware Collective Tree Exploration.** In: Proc. of the Architecture of Computing Systems (ARCS'06)
- Miroslaw Dynia, Andreas Kumlehn, Jaroslaw Kutylowski, Friedhelm Meyer auf der Heide, Christian Schindelhauer: **SmartS Simulator Design.**
- Miroslaw Dynia, Jaroslaw Kutylowski, Christian Schindelhauer, Friedhelm Meyer auf der Heide: **Smart Robot Teams Exploring Sparse Trees.** In: Proc. of the 31st International Symposium of Mathematical Foundations of Computer Science (MFCS'06)
- Miroslaw Dynia, Jaroslaw Kutylowski, Pawel Lorek, Friedhelm Meyer auf der Heide: **Maintaining Communication Between an Explorer and a Base Station.** In: IFIP 19th World Computer Congress, TC10: 1st IFIP International Conference on Biologically Inspired Computing (BICC'06)

Thank you
for
your
attention!



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