Increasing the Connectivity in Ad-Hoc Networks

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Overview

- Motivation: the DeepMap Environment
- Ad-Hoc Networks
- ANSim – an Ad-Hoc Network Simulator
- Increasing the Connectivity in Ad-Hoc Networks
- Outlook

DeepMap: The Idea

- **Develop a virtual tourist guide for the world-famous city of Heidelberg**
- **handheld device to be carried by the tourist**
- **some local data on the disk, but huge collections of data available online:**
  - **compute virtual tours during the planning stage**
  - **present data on specific buildings, even in different historic times, in different media: video, audio, animations, 3D models, maps, etc.**
  - **lead the tourist on his path**
  - **let him communicate within his (virtual) group**
  - **locate users**

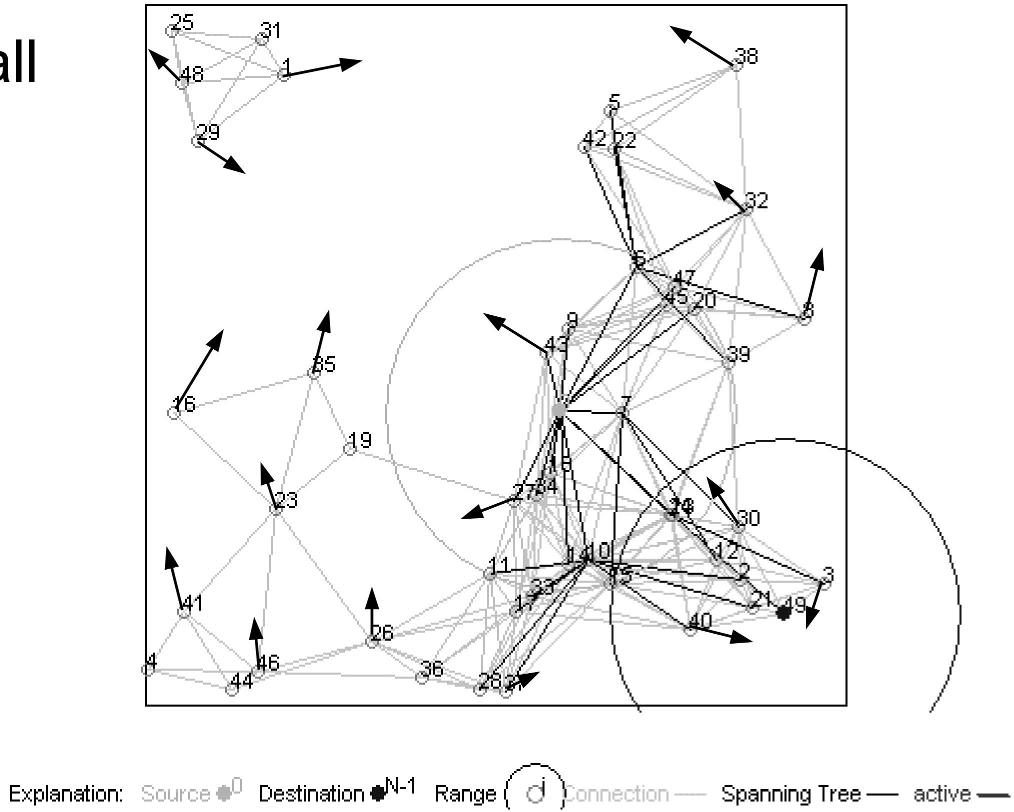
Ad-Hoc Networking

- Question: now we have many mobile devices in a certain area – can‘t we make use of them for more than just as user devices?
- Example: increase of hot spot size by using these mobile devices as relay stations, i.e. by building **ad-hoc networks**
- Ad-Hoc Network Definition (Charles Perkins):
  - Wireless Networks where the nodes are far enough apart so that not all of them are in reach of each other
  - The nodes are able to assist each other in the process of delivering the packets of data.
  - Mobility is optional
- Potential Applications:
  Sensor-Networks, Telematics, emergency Networks

Project:ANSim

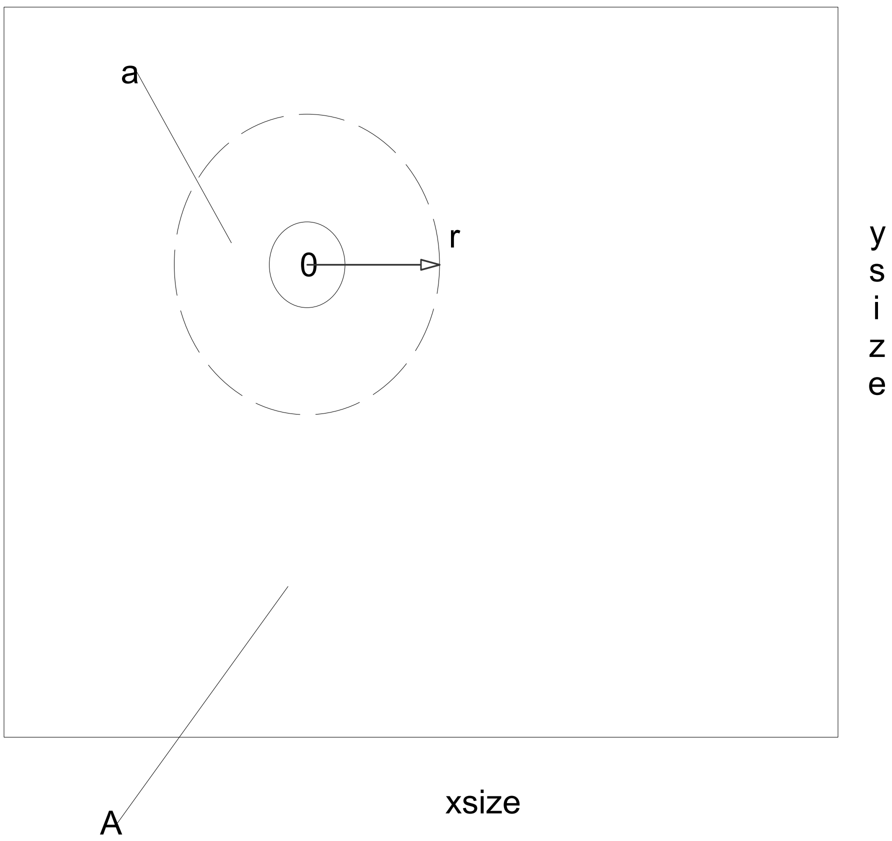
- Immediate question: when is it worth trying?
  - Few stations with small transmission radius
  - Result: no connection or frequent disruption
  - Can even be couter-productive
- We investigate this question doing simulations (analytical solutions not feasible)
- → Development of the ANSim simulator

Ad Hoc Networks Simulation



Model for the Simulation

- Model in the geometry of two dimensions R^2
  - Area *A*
  - *N* Nodes uniformly distributed within *A*
  - Node positions are independent of each other $P_B <> f(P_A)$
  - Transmission radius *r*
- free-space loss
  - distance *d* between 2 Nodes smaller than *r*
    => transmission possible
  - $d>r$ => **no** Transmission



ANSim Demo

Click to Start ANSim

First ANSim results

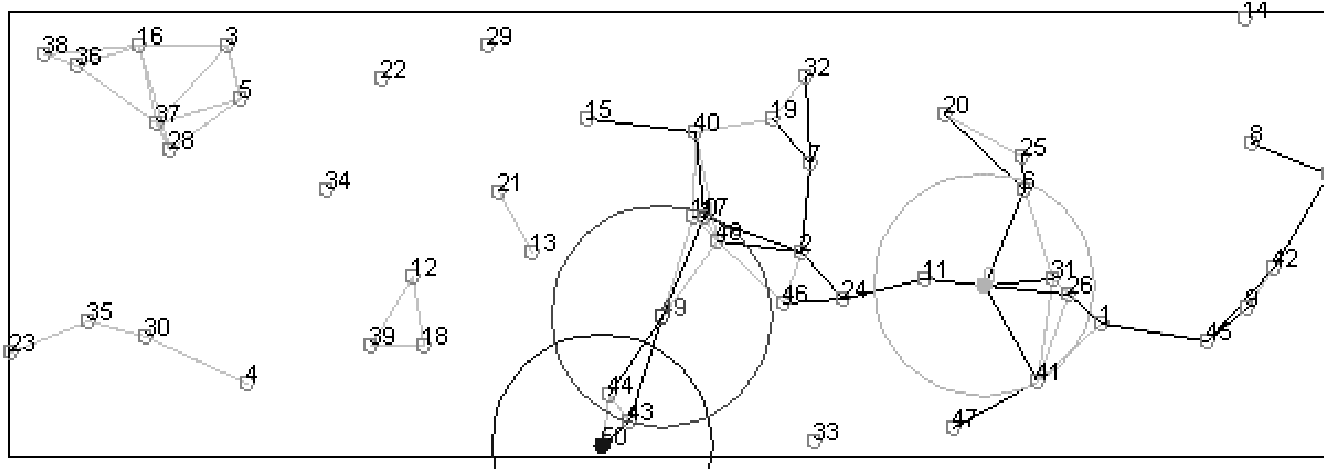
- Scenario: area of 1000m x 1000m, transmission range 250m
- Many devices are necessary to be able to set up connections with a certain probability:
  - When the full area is covered 5 times by transmission range circles, the probability is 80%.
  - With a degree of coverage of 8 it is close to 100%.
- When 95% is desired, every node needs to have (depending of the area‘s shape) 5 to 15 direct neighbors, in the above scenario 7,7.
- Big problem: usage of same frequency bands leads to disturbances (not covered in ANSim)

Maintaining Connectivity

- Nodes are mainly interested in doing their applications‘ job
- They are typically not interested in maintaining the network
- So, when there currently is a connection important for a certain application that is built by two nodes coming from a different application, the connectiuon might quickly break

A possible Solution for low Connectivity

Robot N_{49} enabling connection between N_0 & N_{50}



- Idea: introduce a small number of mobile nodes called *robots*
- *Robots* act as "Maintainers" of the network
- challenge is to locate the optimal destination for a *robot* *Aspects are:*
  - Many broken links to choose from
  - Time necessary to reach the destination
  - What is the maximum benefit for the whole network
  - Coordination with other robots

Robots Maintaining the Network

- Robots move according to a random pattern equivalent than the standard nodes
- Robots follow a positioning algorithm & move with *v* = *infinite* (Reference)
- Robots follow a positioning algorithm and move with the maximum velocity of the standard nodes
- Stationary robots according to the results of the previous steps

Positioning Algorithm

```
Begin
  create robots list
  Do
      - cluster analysis of nodes without
                 elements of the robots list
      - find a robot and a position with
            maximum Cost-/Benefit Relationship
      - send the robot to that position and
            remove it from robots list
  until robots list==empty or Number of
  Clusters==1
End
```

Benefit & Cost Function Simple Approach

- **Benefit function** for Nodegroup (Cluster) G_j and G_k (with N(x) = number of nodes in x)

$$b(G_j, G_k) = N(G_j) \cdot N(G_k)$$

- **Cost function** for Robot N_r to connect G_j and G_k

$$c(G_j, G_k, N_r) = \frac{d(G_j, G_k)}{r}\left(1 + \frac{d(P(j,k), N_r)^2}{r^2}\right)$$

Optimization Details

- A network has N(>=1) isolated nodegroups
- The size of the Nodegroups is defined as
  $N(G_j(t))$= number of Nodes in Nodegroup
- The probability that two randomly chosen Nodes in the network are connected is:

$$p_{ges}(t) = \sum_{i=1}^{N(t)} \frac{N(G_i(t))^2}{N^2} = \frac{1}{N(t)^2} \sum_{i=1}^{N(t)} N(G_i(t))^2$$

- Our goal to maximize $p_{ges}(t)$ in the time interval $[t_1;t_2]$

$$p_{opt}(t_1, t_2) = max(\int_{t_1}^{t_2} p_{ges}(t)dt)$$

Optimization Details (2)

- One robot can interconnect two nodegroups $G_{l,}$ G_m.
- We define the interval $[t_1;t_2]$ so that $N(G_i(t))$ does not change for all nodegroups.
- The number of nodes does not change.

$$p_{opt}(t_1, t_2) = max(\int_{t_1}^{t_2} \frac{1}{N(t)^2} \sum_{i=1, i \neq l, i \neq m}^{N(t)} N(G_i(t))^2 + N(G_{lm}(t))^2 dt)$$

...

$$= \int_{t_1}^{t_2} \frac{1}{N(t)^2} \sum_{i=1}^{N(t)} N(G_i(t))^2 + 2max(N(G_l(t))N(G_m(t)))dt$$

$\Rightarrow$Select 2 Nodegroups so that $N(G_l(t))*N(G_m(t))$ is maximum.

Optimization Details (3)

See Simulation

opti.jar

for a slow motion illustration

(red links: goal for a robot folloowing optimization computation)

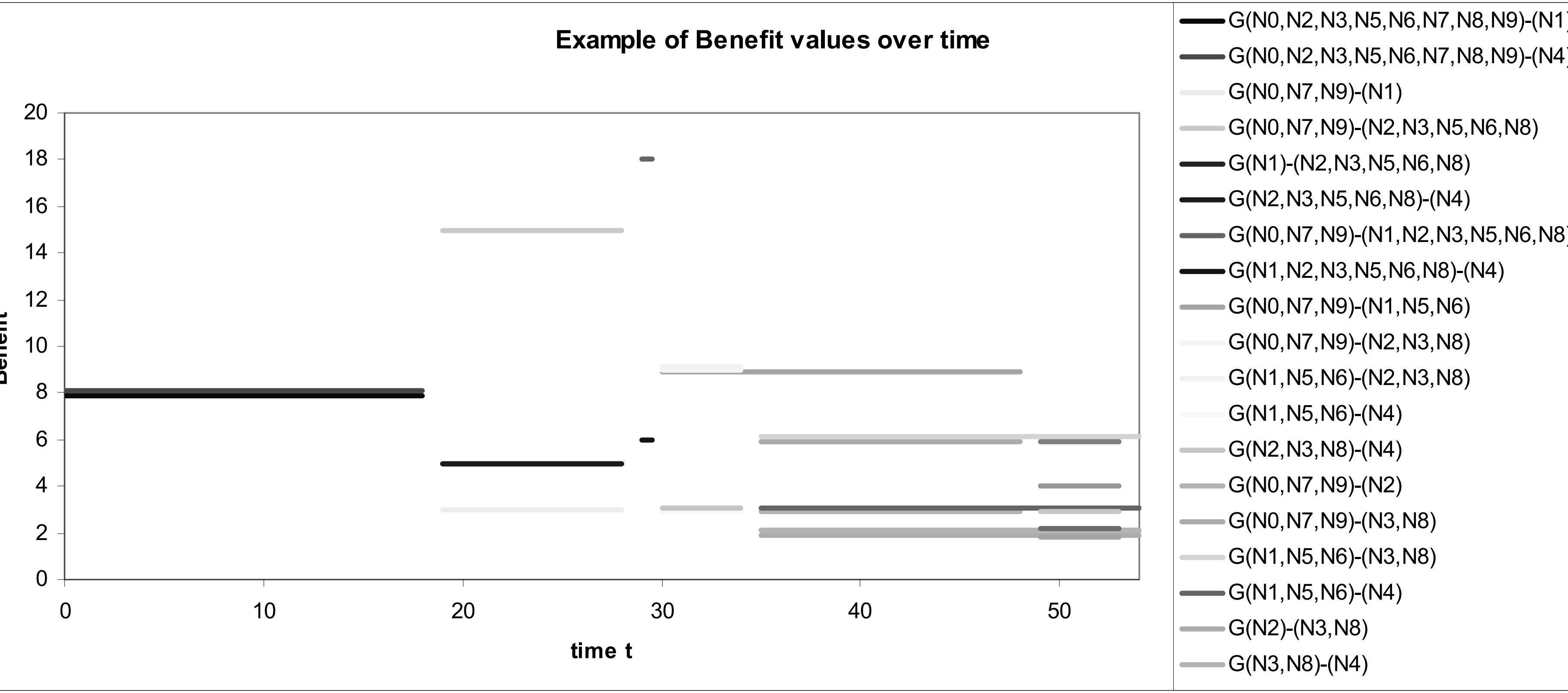
Parameters:

1000x1000m, 10 Nodes, range=250m,

Random Waypoint Model, v=[0:10m/s], stop=0s,

Optimization Details (4)

- Szenario Without Robots



Simple Cost Movement

See Simulation

ansimold.jar

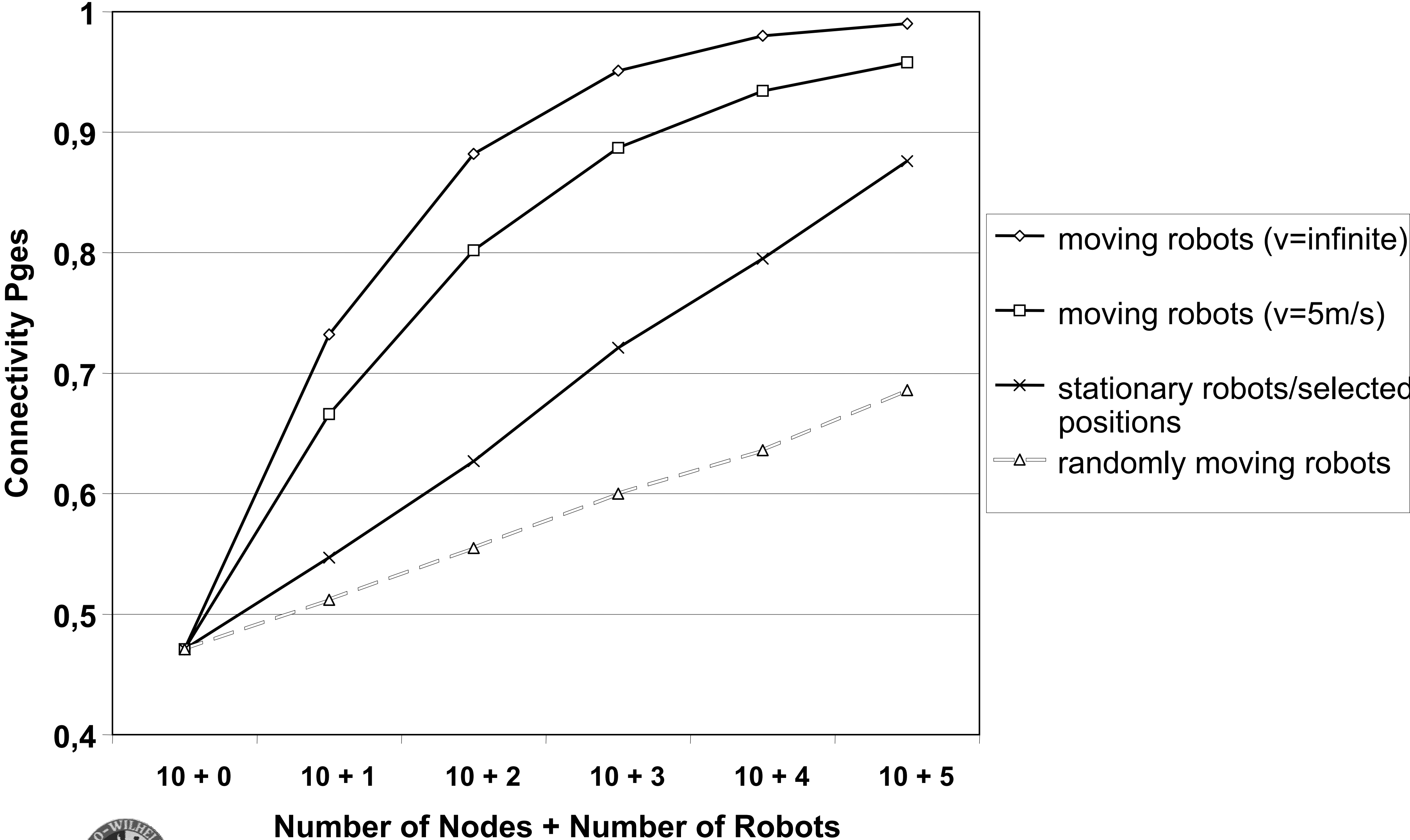
for a slow motion illustration

Parameters:

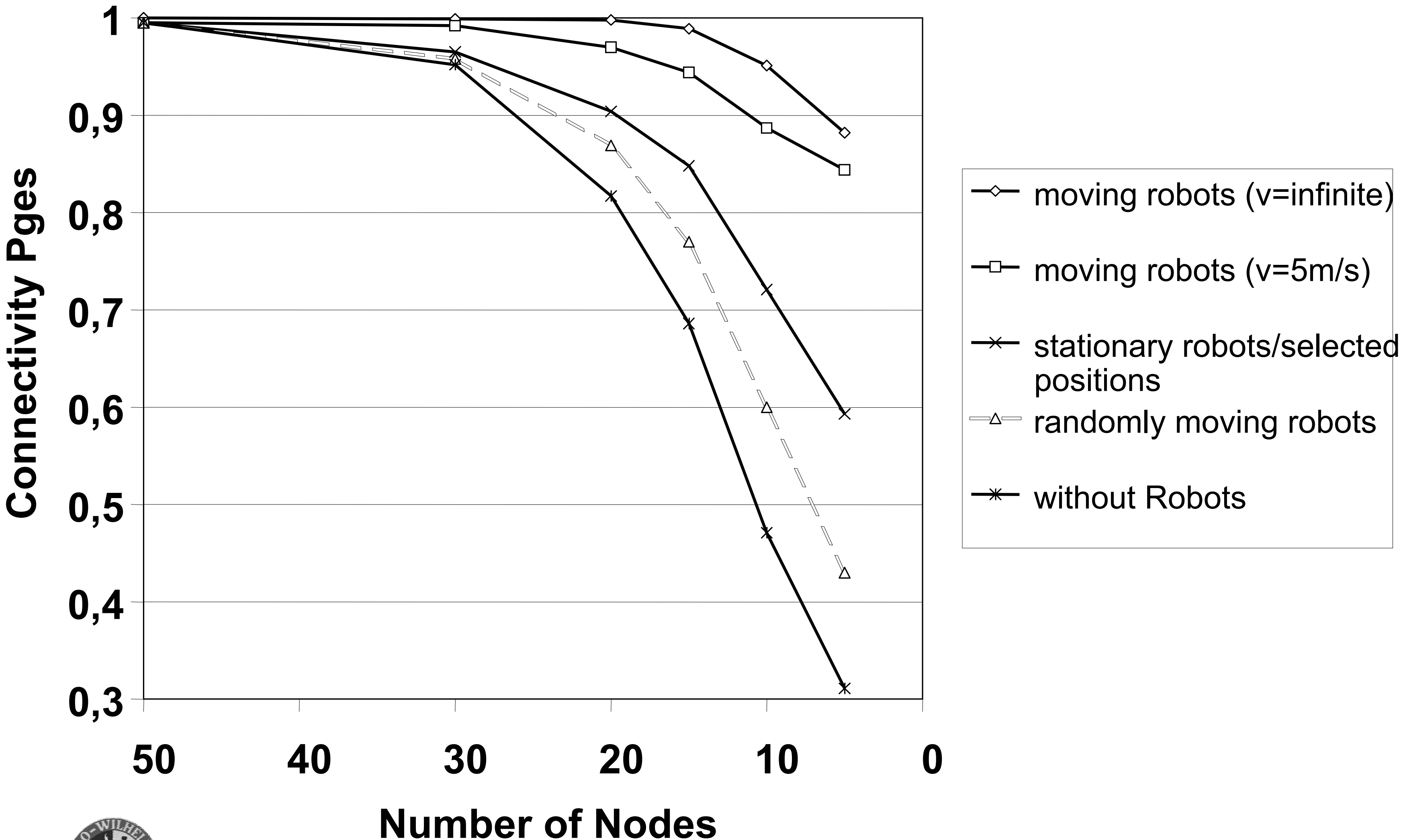
1000x1000m, 10 Nodes, range=250m,

Random Waypoint Model, v=[0:10m/s], stop=0s,

Connectivity for 10 MANET Nodes Random Waypoint Mobility

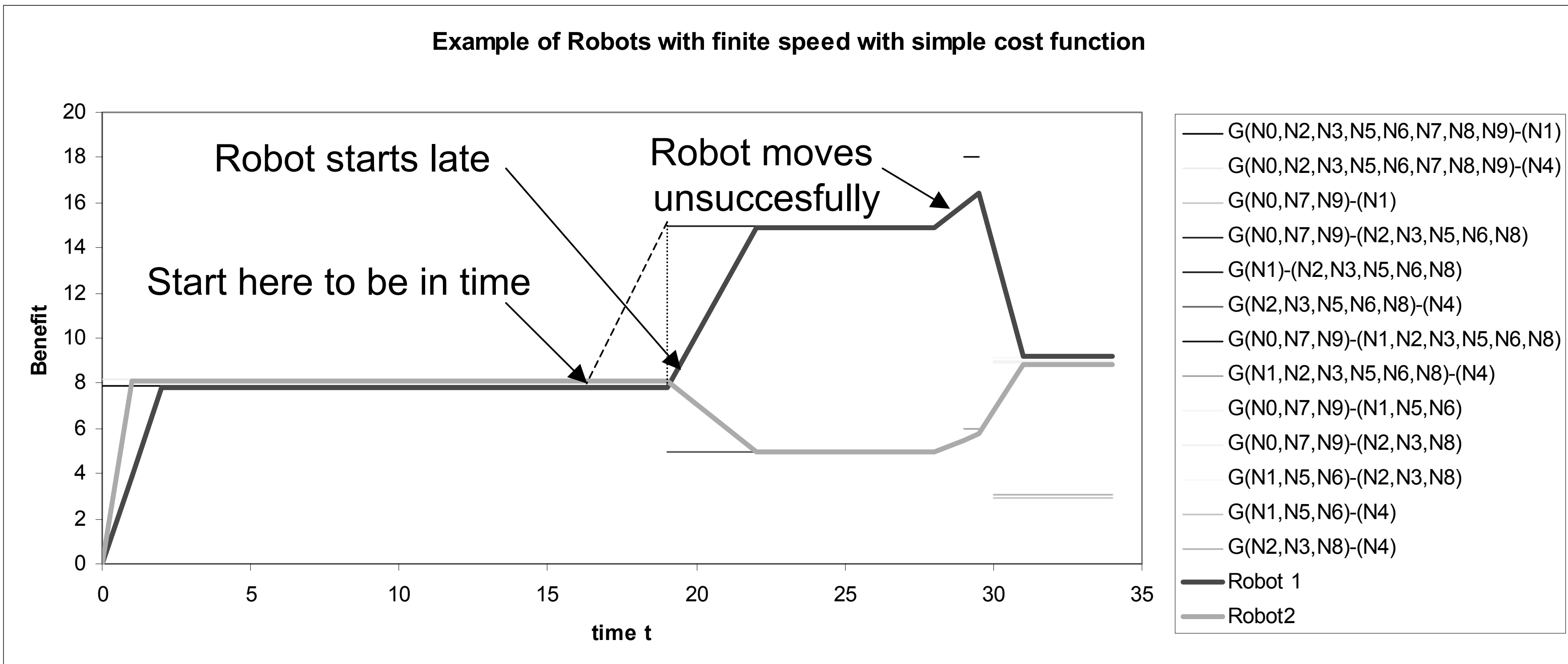


Connectivity for MANET Nodes with 3 Robots (Random Waypoint Mobility)



Simple Cost function

- Szenario with Robots & finite speed (here very fast)
- „Robots need time to move from one broken link to the other“



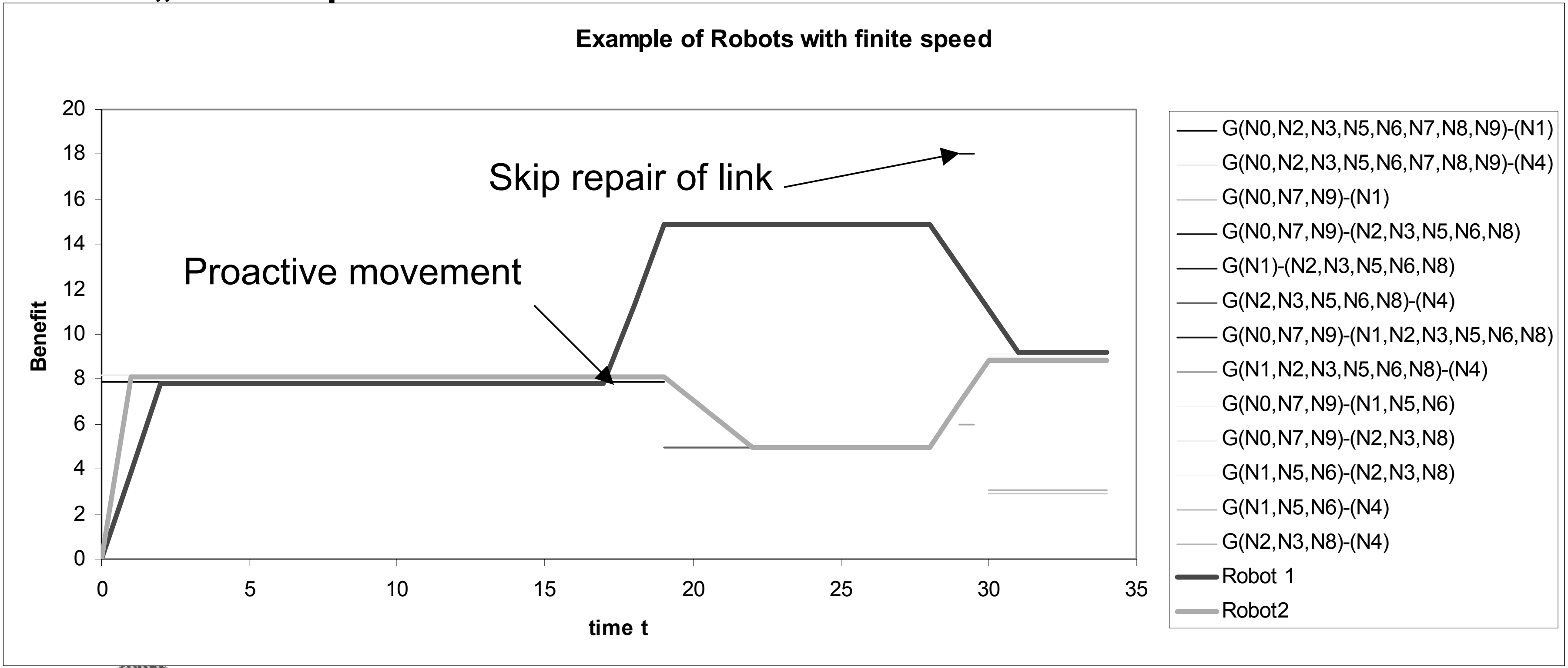
How to find a better moving pattern for the robots ?

$$p_{opt}(t_1, t_2) = max(\int_{t_1}^{t_2} p_{ges}(t)dt)$$

- Predict the future network topology from the movement of the nodes in the past.
- Generate benefit functions for repairing links in the predicted future.
- Use a sliding window technique for limiting the complexity (do not consider links that are too far in future)
- Assign robots to links.

Proactive Robots Illustration

- Szenario with Robots & finite speed (here very fast)
- „Robots start before links break“
- „… skip broken links that can‘t be reached in time



Proactive Movement

See Simulation

ansimnew.jar

for a slow motion illustration

Parameters:
1000x1000m, 10 Nodes, range=250m,
Random Waypoint Model, v=[0:10m/s], stop=0s,
2 Robots with knowledge of all node positions

Status of Proactive Movement

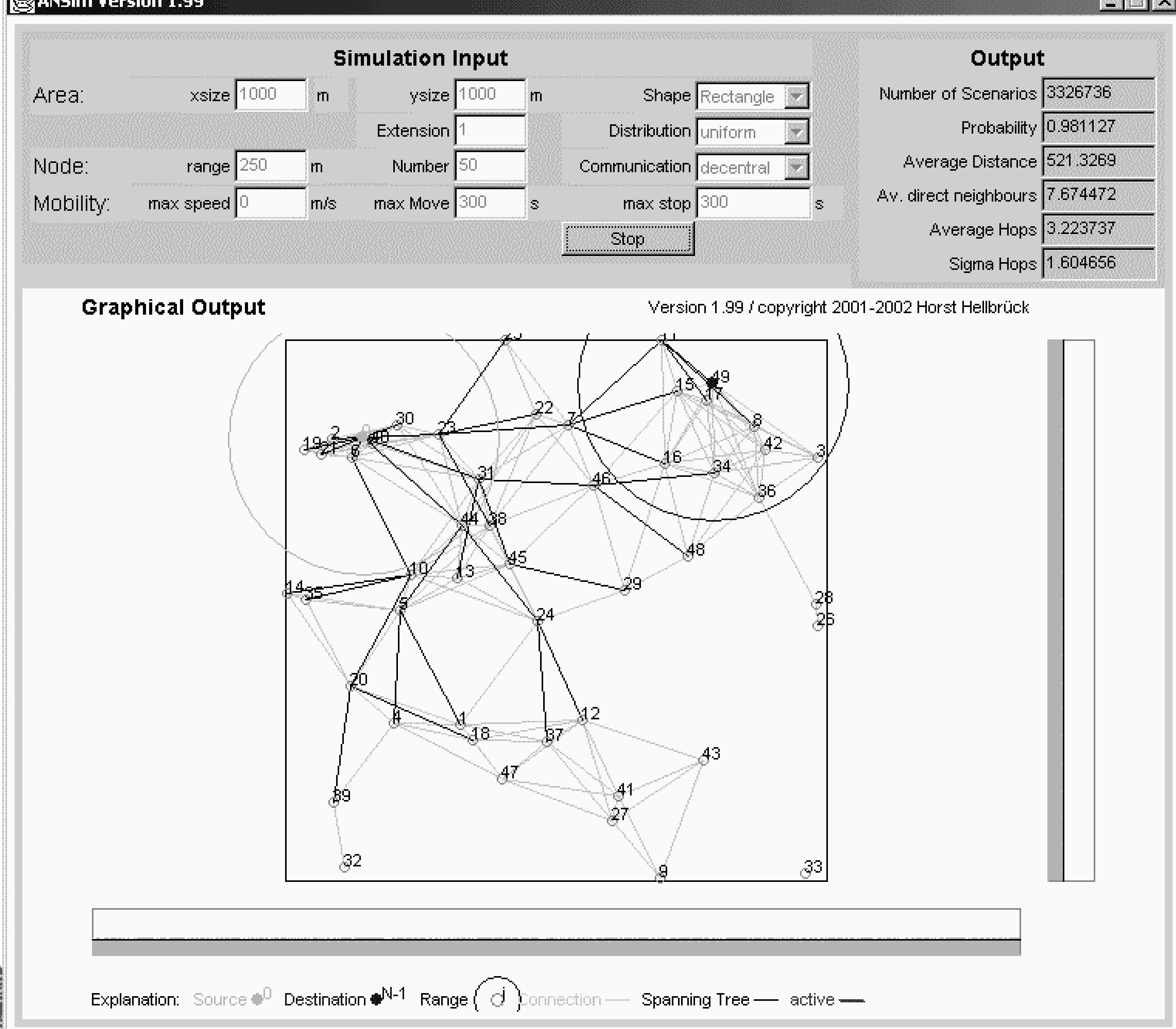
- No final results available yet
- Trade off between complexity and usefulness of the algorithm is still under investigation (limited computational power of the robots).
- More details available soon.

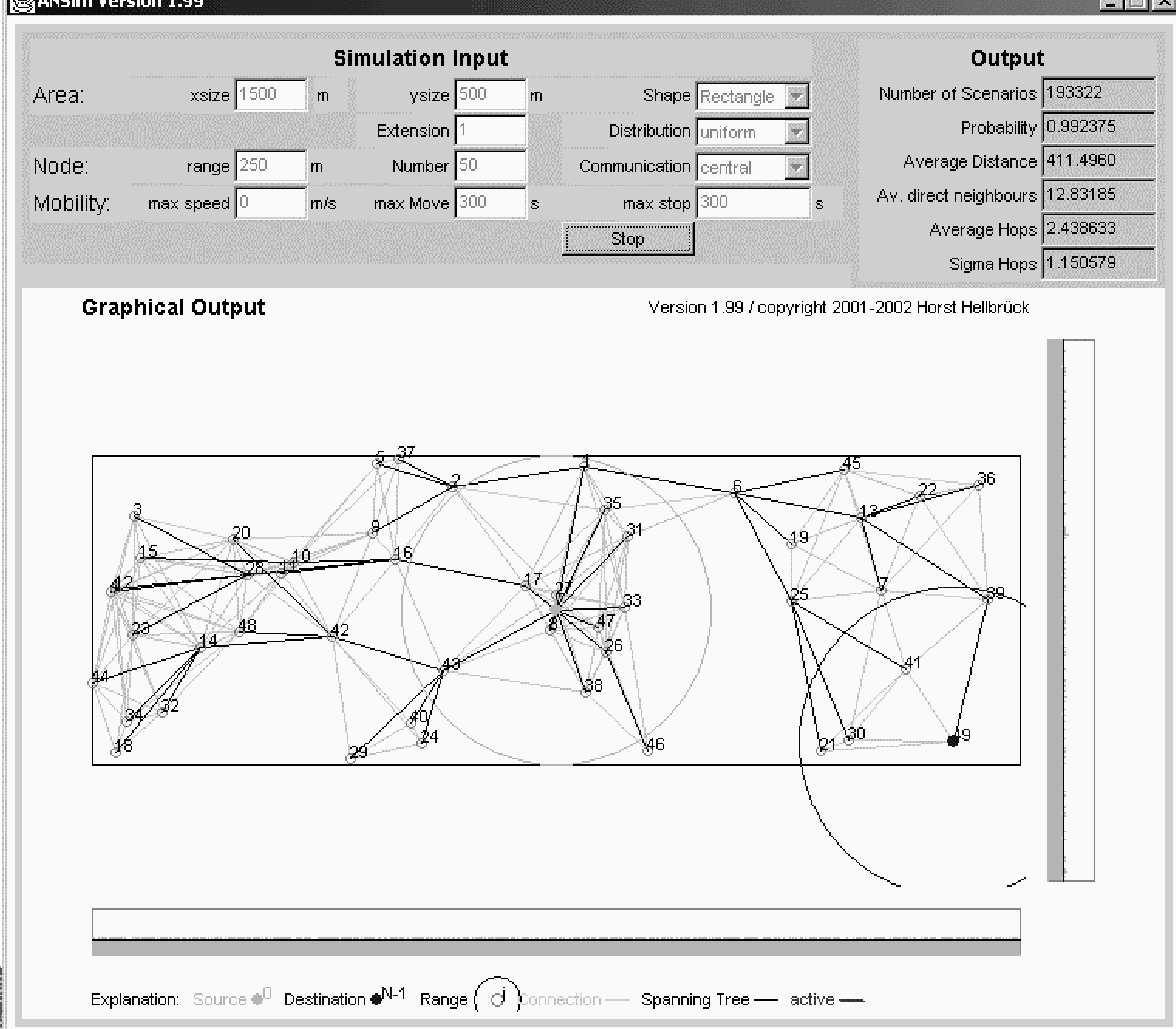
Conclusions

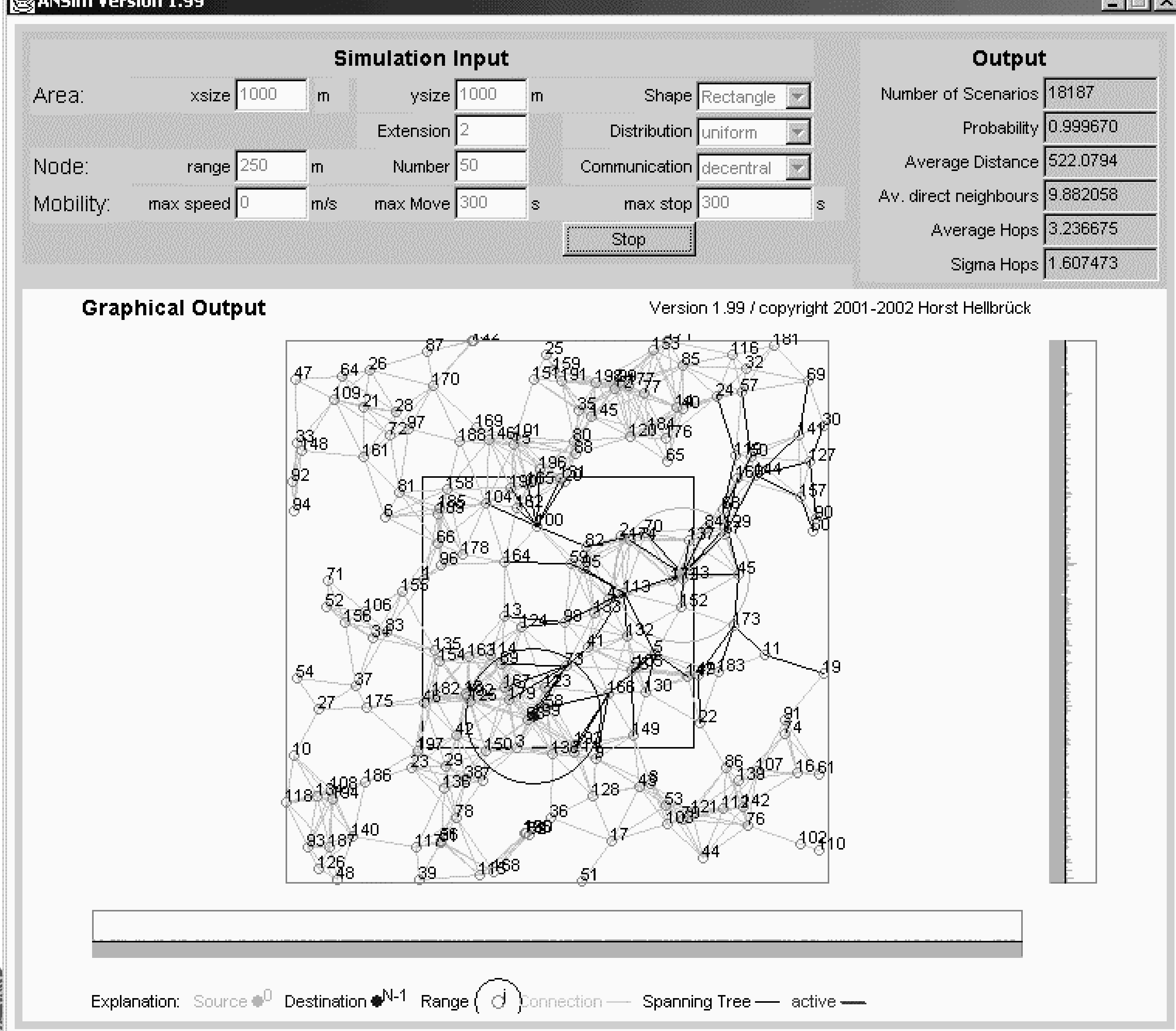
- Based on a simple theoretical model, we simulated connection probabilities of Ad-Hoc networks.
- The tool ANSim enables the investigation of autonomous robots introduced into the network and running a distributed positioning algorithm.
- Mobile robots significantly improve the connectivity of mobile Ad-Hoc networks and help to maintain links between nodes in the case of decreasing number of nodes.
- Designers of Ad-Hoc networks as well as researchers can benefit from this tool by deriving scenarios for detailed investigations of protocols e.g. by means of *ns*-2.

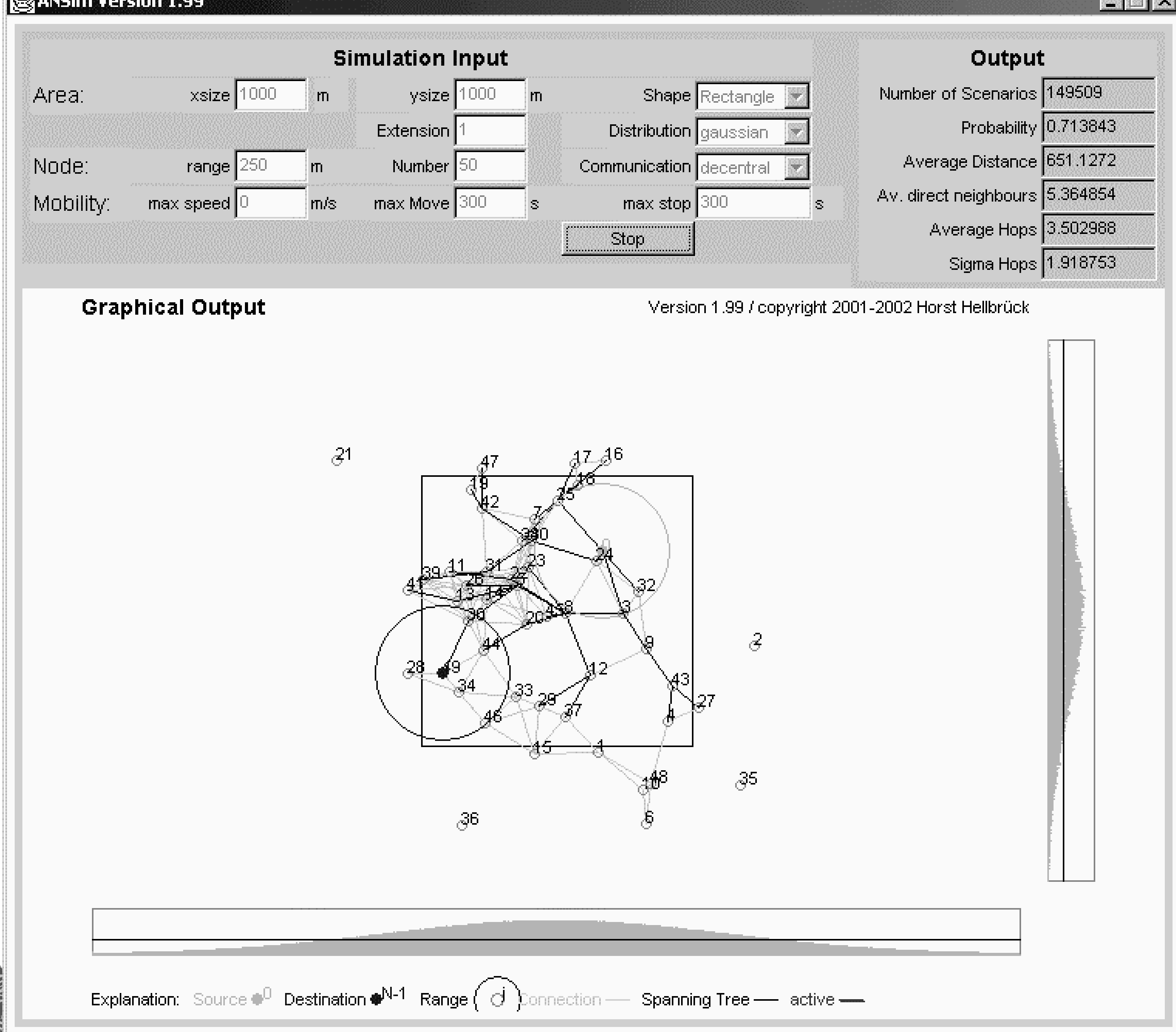
Future Work

- An important future project is a modification of the positioning algorithm to cope with the fact that the robots just know the locations of the connected nodes and do **not** have an overall picture of the network.
- A further improvement already planned is the coordination of robots so that two or more robots together fill the gaps between isolated node groups.
- => These extensions are in development.

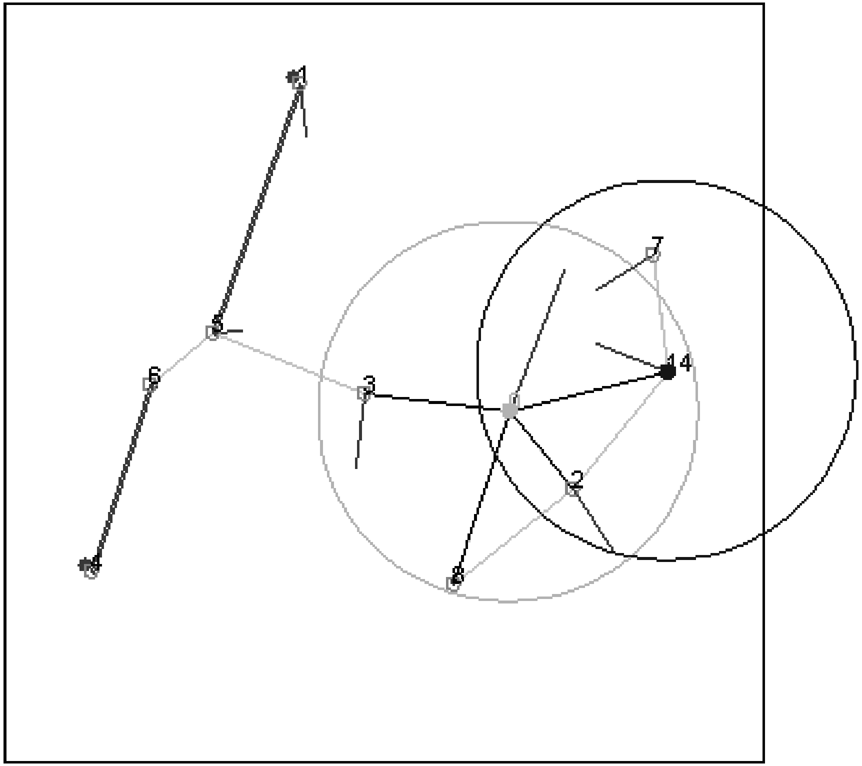

ANSim Version 1.99
Simulation Input
Area: xsize 1000 m ysize 1000 m Shape Rectangle
Extension 1 Distribution uniform
Node: range 250 m Number 50 Communication decentral
Mobility: max speed 0 m/s max Move 300 s max stop 300 s
Stop
Output
Number of Scenarios 3326736
Probability 0.981127
Average Distance 521.3269
Av. direct neighbours 7.674472
Average Hops 3.223737
Sigma Hops 1.604656
Graphical Output
Version 1.99 / copyright 2001-2002 Horst Hellbrück
Explanation: Source 0 Destination N-1 Range d Connection Spanning Tree active


ANSim Version 1.99
Simulation Input
Area: xsize 1500 m ysize 500 m Shape Rectangle
Extension 1 Distribution uniform
Node: range 250 m Number 50 Communication central
Mobility: max speed 0 m/s max Move 300 s max stop 300 s
Stop
Output
Number of Scenarios 193322
Probability 0.992375
Average Distance 411.4960
Av. direct neighbours 12.83185
Average Hops 2.438633
Sigma Hops 1.150579
Graphical Output
Version 1.99 / copyright 2001-2002 Horst Hellbrück
Explanation: Source 0 Destination N-1 Range d Connection Spanning Tree active

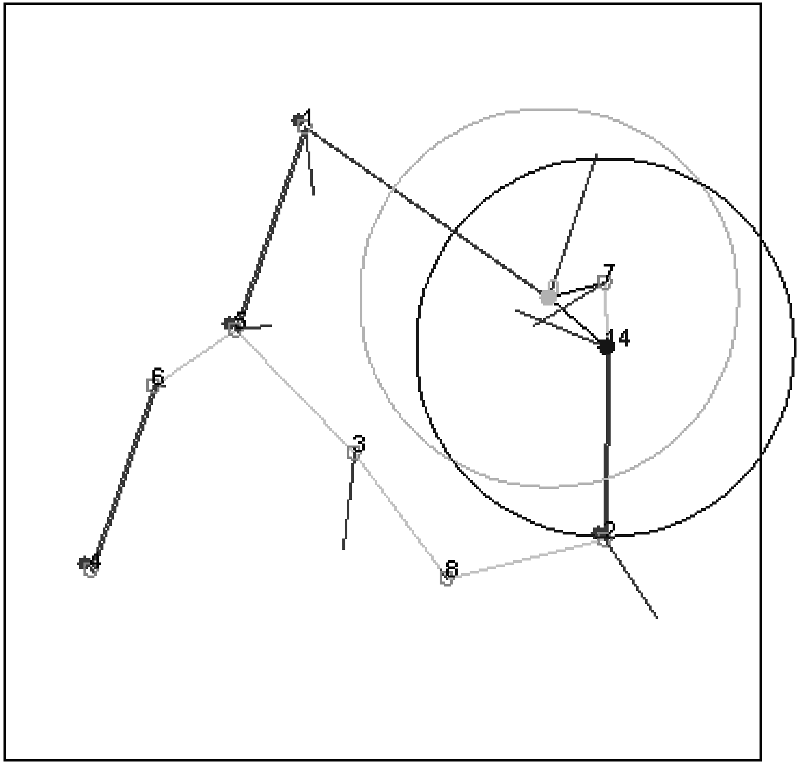

ANSim Version 1.99
Simulation Input
Area: xsize 1000 m ysize 1000 m Shape Rectangle
Extension 2 Distribution uniform
Node: range 250 m Number 50 Communication decentral
Mobility: max speed 0 m/s max Move 300 s max stop 300 s
Stop
Output
Number of Scenarios 18187
Probability 0.999670
Average Distance 522.0794
Av. direct neighbours 9.882058
Average Hops 3.236675
Sigma Hops 1.607473
Graphical Output
Version 1.99 / copyright 2001-2002 Horst Hellbrück
Explanation: Source 0 Destination N-1 Range Connection Spanning Tree active


ANSim Version 1.99
Simulation Input
Area: xsize 1000 m
ysize 1000 m
Shape Rectangle
Extension 1
Distribution gaussian
Node: range 250 m
Number 50
Communication decentral
Mobility: max speed 0 m/s
max Move 300 s
max stop 300 s
Stop
Output
Number of Scenarios 149509
Probability 0.713843
Average Distance 651.1272
Av. direct neighbours 5.364854
Average Hops 3.502988
Sigma Hops 1.918753
Graphical Output
Version 1.99 / copyright 2001-2002 Horst Hellbrück
Explanation: Source 0 Destination N-1 Range Connection Spanning Tree active

Optimization Details 3

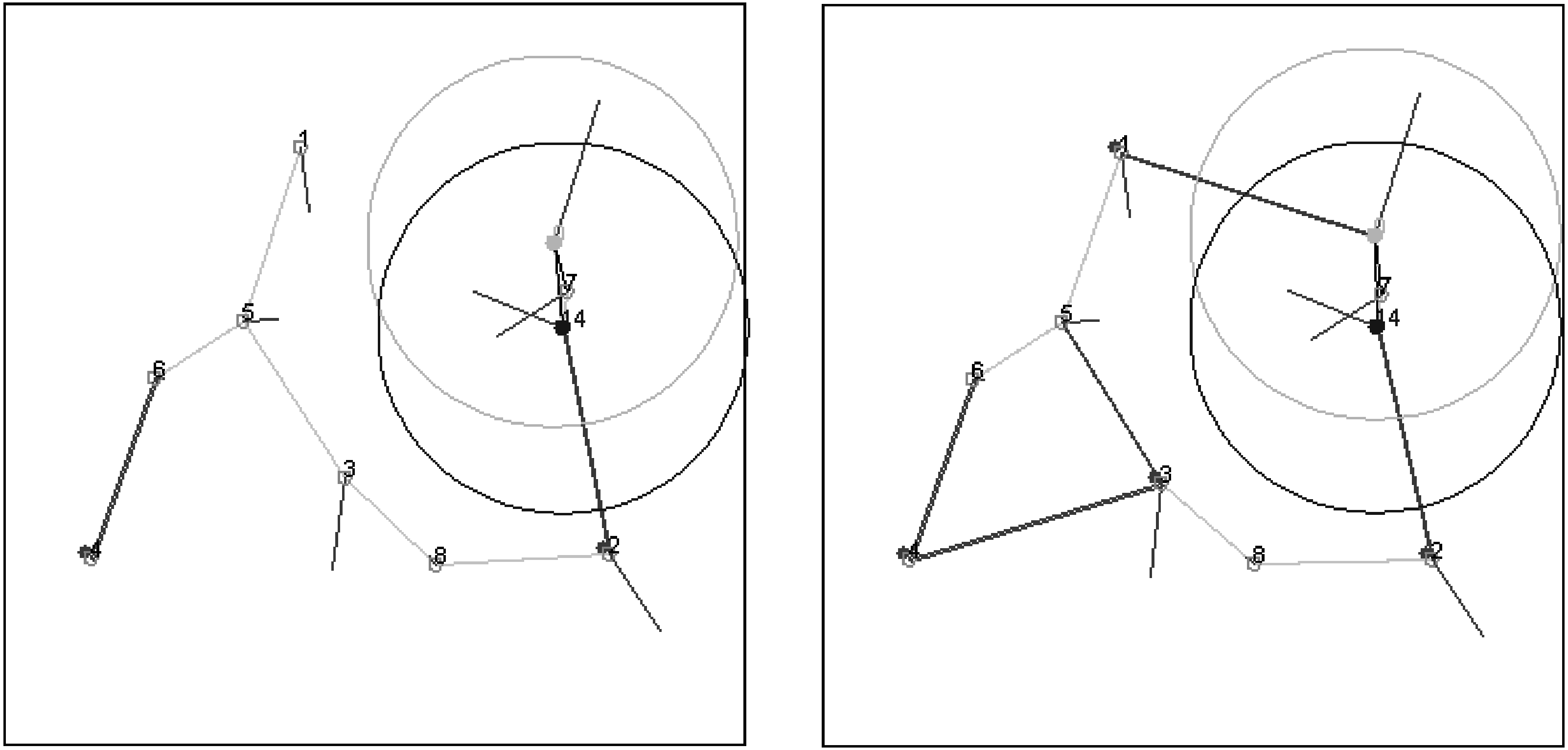


t = 0 s



t = 18 s

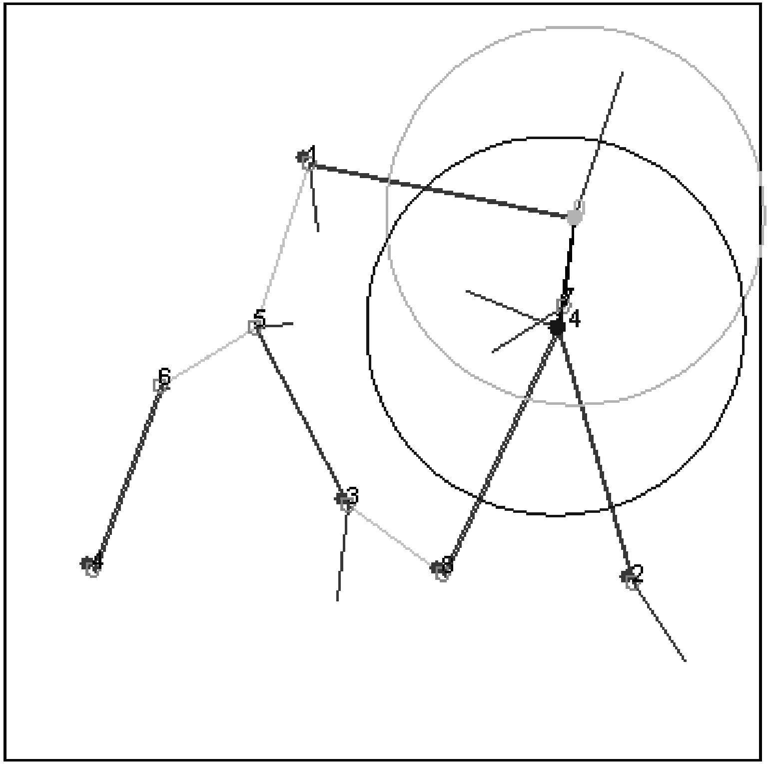
Optimization Details 4



t = 29 s

t = 30 s

Optimization Details 5



t = 33 s

...