Communication and Computation in DCSP Algorithms

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Testing DisCSP algorithms in real environments

The need for realistic DisCSP benchmarks

- We need problem instances that capture the structure of real DisCSP
- But we need an easy way to generate instances with different constrainedness

Our proposal: a distributed resource allocation problem

The effect of the communication network

- In real scenarios, agents will experience the delays of the communication network
- We should investigate how delays affect the performance of the algorithms

Our proposal: a discrete event-simulator able to simulate different delay distributions

Contents

- DisCSP
- SensorDCSP benchmark
- DisCSP algorithms
- Complexity profiles of DisCSP algorithms on SensorDCSP
- The effect of the communication network load
  - Delays actively added by the Agents
  - Delays because of the network load

Distributed Constraint Satisfaction Problem (DisCSP)

Agents need to solve different CSPs

- Local constraints (within Agents)
- Global constraints (between Agents)

How do Agents solve it ?

- Local constraints: computation
- Global constraints: computation + **communication**

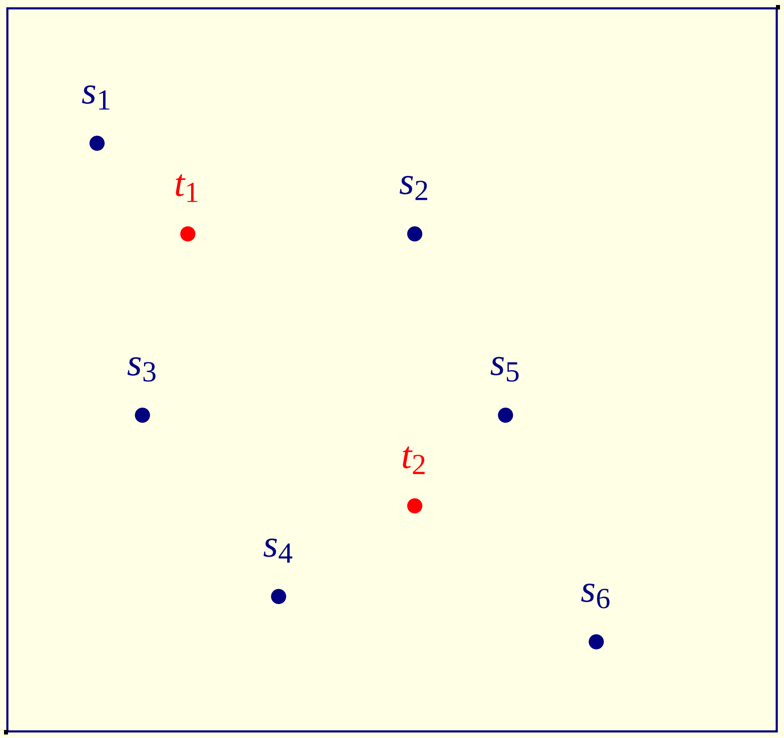
What is the impact of the **communication network** in the performance ?

SensorDCSP benchmark

Input:

- Multiple sensors (s_i) and mobiles (t_j) randomly scattered
- Constraints:
  - sensor visibility bipartite graph (P_v): sensors that can track a given mobile
  - every sensor can track at most one mobile
  - sensor compatibility graph (P_c): compatibility relation between sensors

Objective: Assign to each mobile 3 pair-wise compatible sensors that can track it



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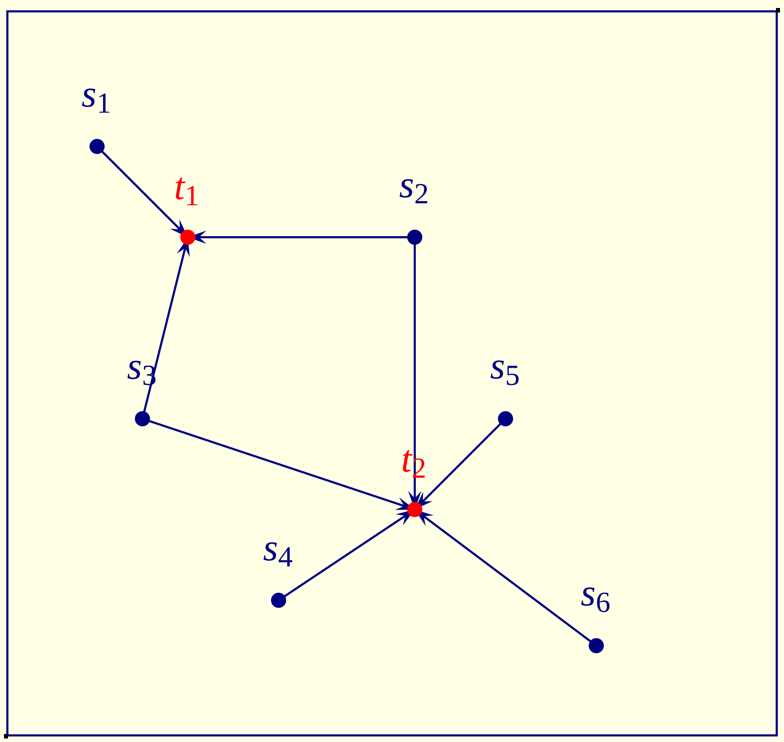

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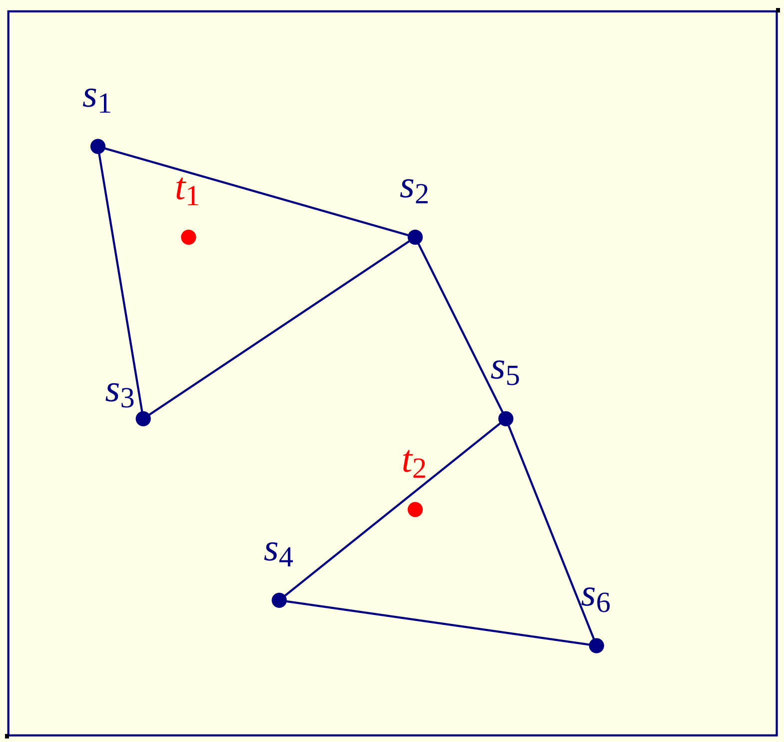

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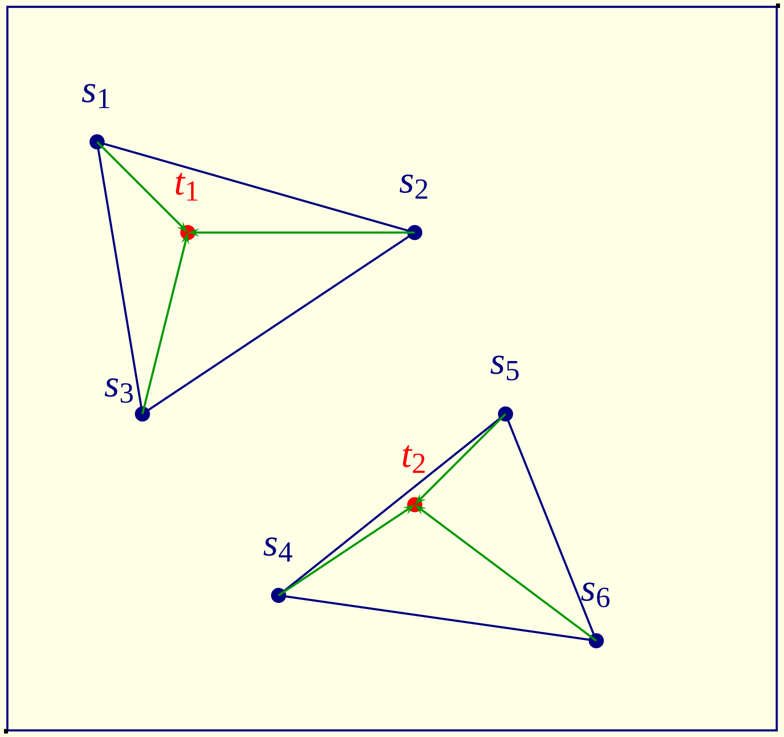


DisCSP algorithms

Messages exchanged:

- **Ok**: inform about assignments to its neighbors
- **nogood**: ask a neighbor to change its assignment

Algorithms:

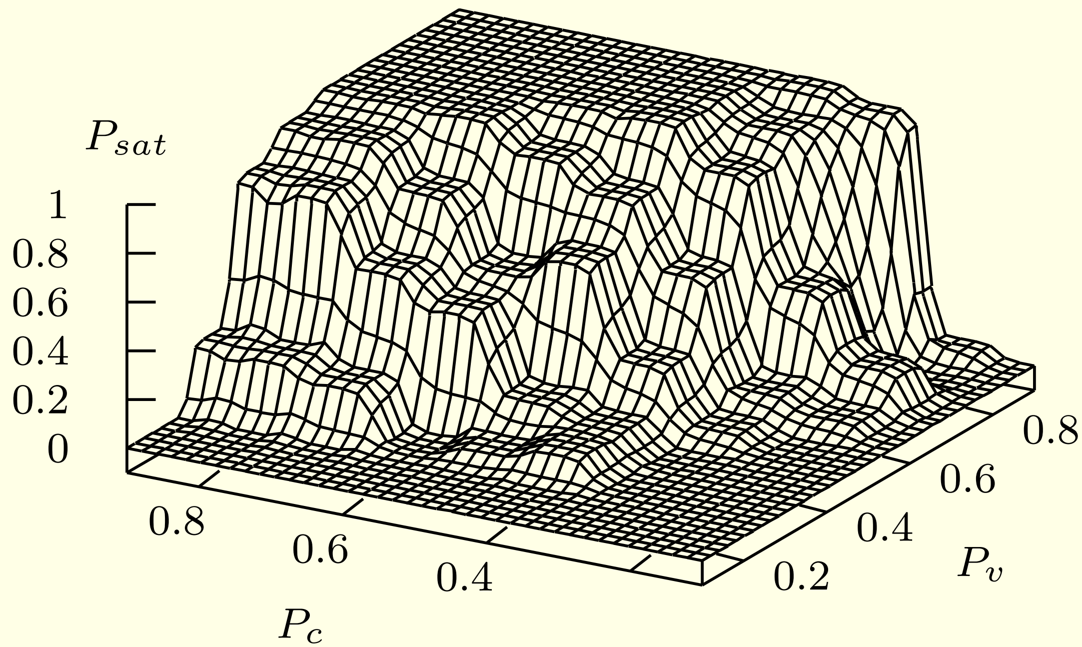
- Asynchronous Backtracking (ABT)
  - static ordering between agents
  - random selection among values consistent with higher (priority) agents
- Asynchronous Weak-Commitment Search (AWC)
  - dynamic priority ordering
  - random selection among values consistent with higher agents and that minimize constraint violations with lower agents

Implemented using a **distributed discrete-event network simulator**

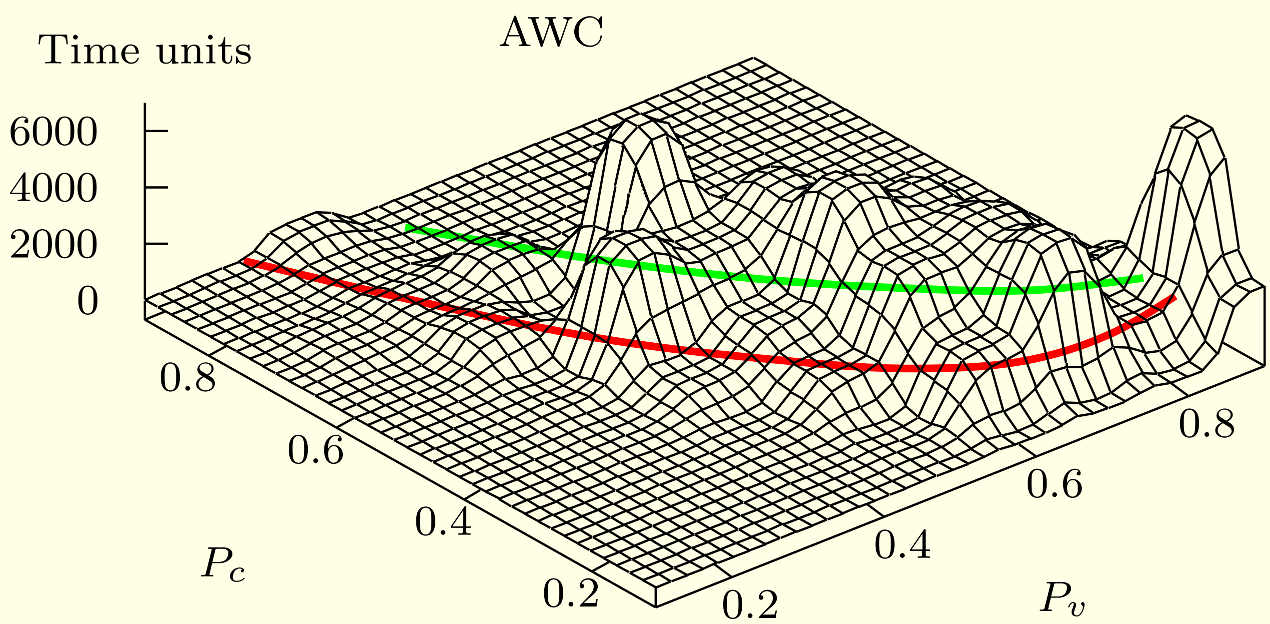
Complexity profiles of DisCSP algorithms on SensorDCSP

- Experimental scenario
  - Inter-agent communication delays: exponentially distributed, mean 1 time unit
  - 3 mobiles and 15 sensors. P_c and P_v ranging from 0.1 to 0.9
  - 19 instances per point. 9 independent runs for instance

Ratio of satisfiable instances

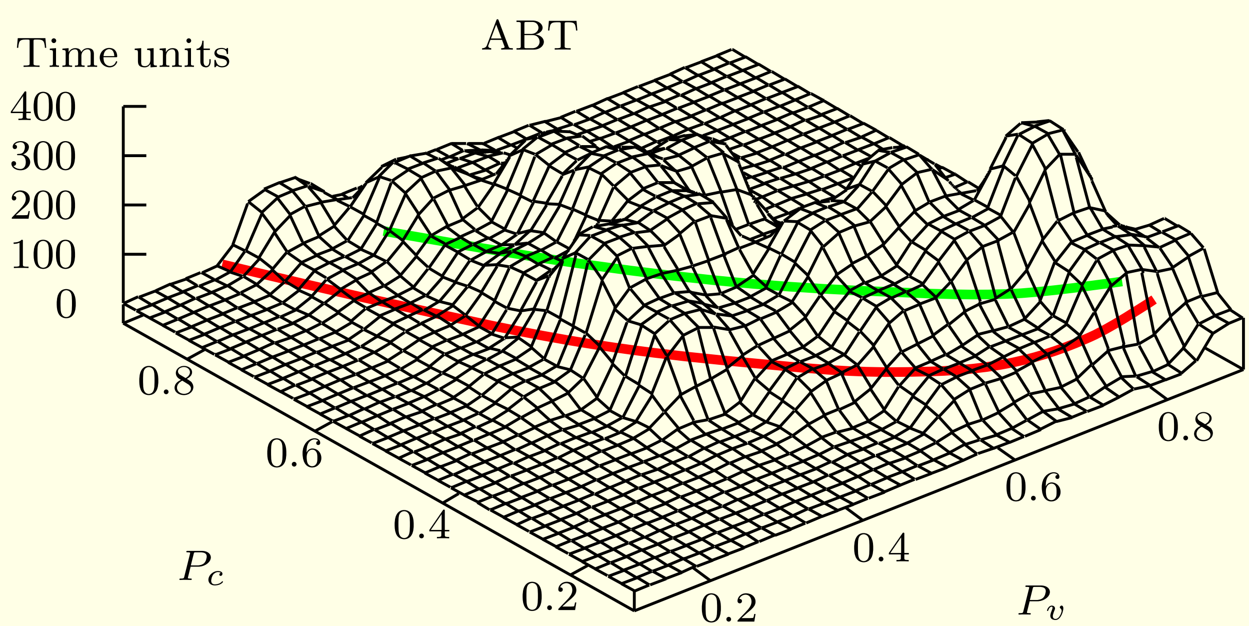


Mean solution time



$P_{sat} = 0.8$

$P_{sat} = 0.2$



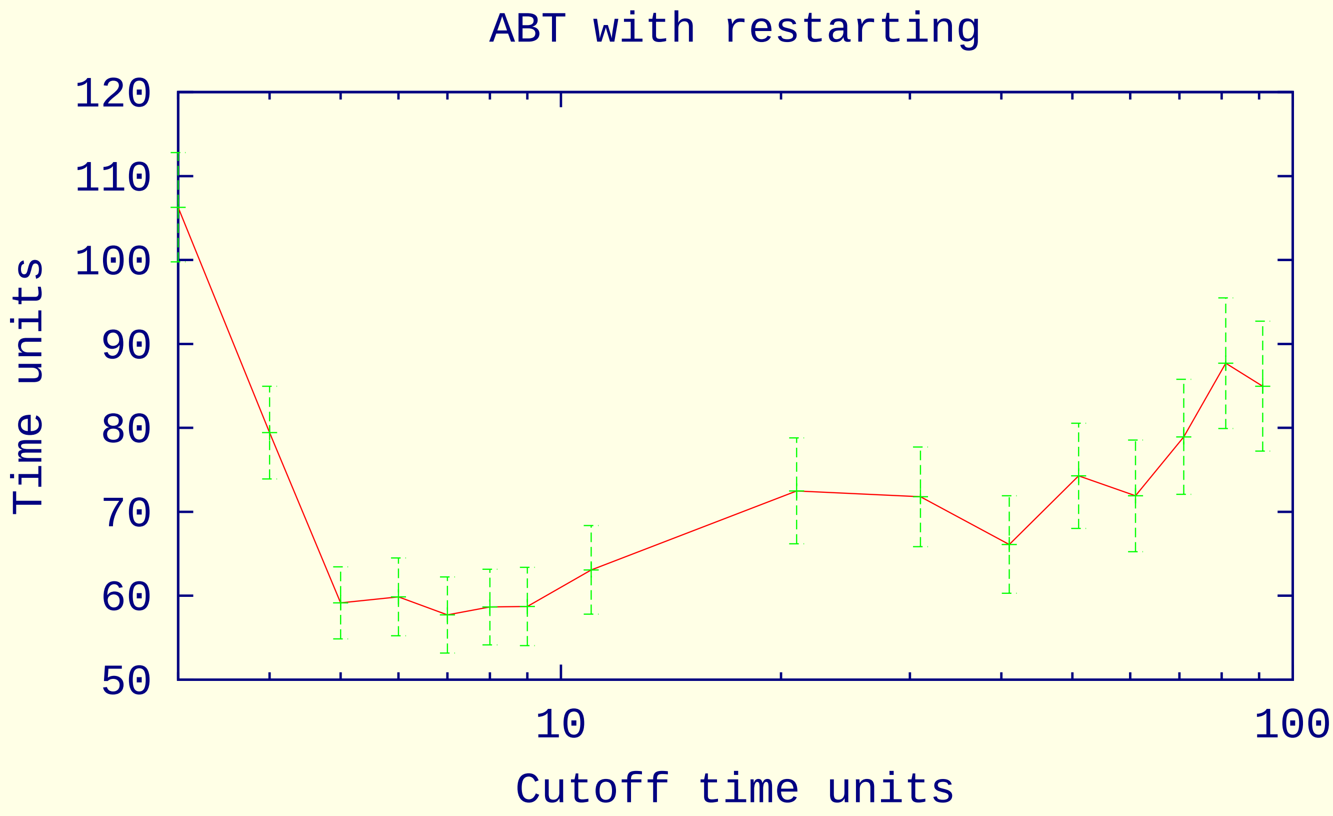
NP-complete for $P_c < 1$

harder for lower P_c

Restarting strategy for ABT

- Higher priority agent initiates the restarting of the search
- Performance depends on cutoff time
- Not suitable for AWC due to its inherent dynamic priority behavior

Mean solution time on a hard instance



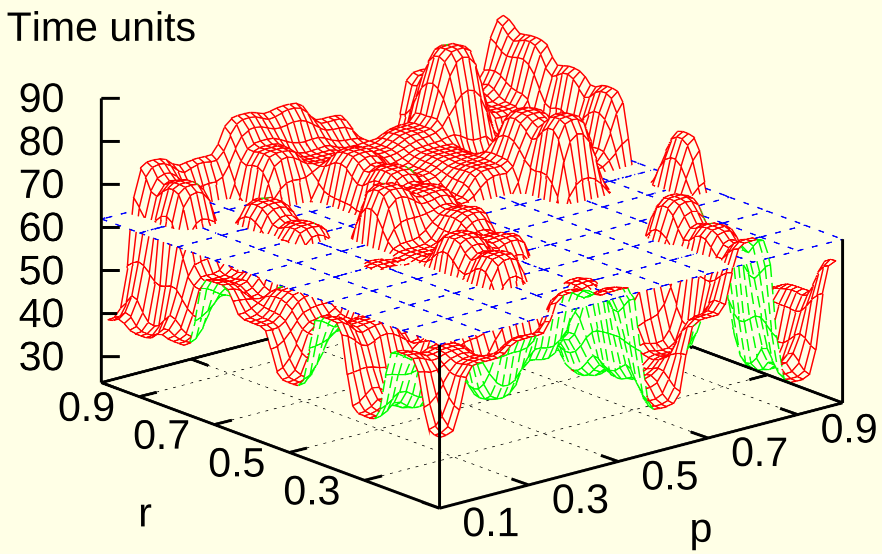
Active delaying of messages

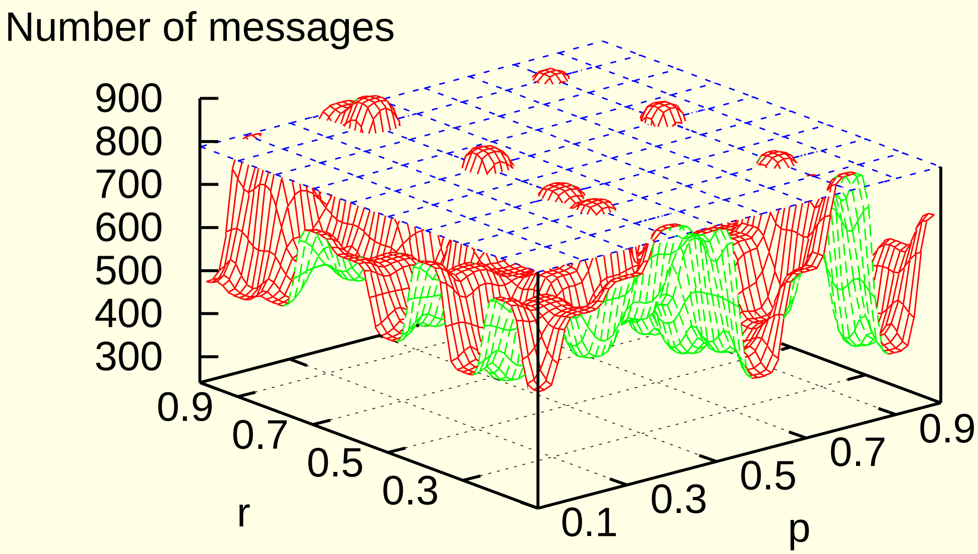
- Adding delay introduces a controlled source of randomization.

- Controlling the level of randomization:

  - p, probability that an agent adds extra delay
  - $0 \leq r \leq 1$, amount of added delay (fraction of the delay of the link)

Median values for a hard instance (AWC in a fixed delay scenario)



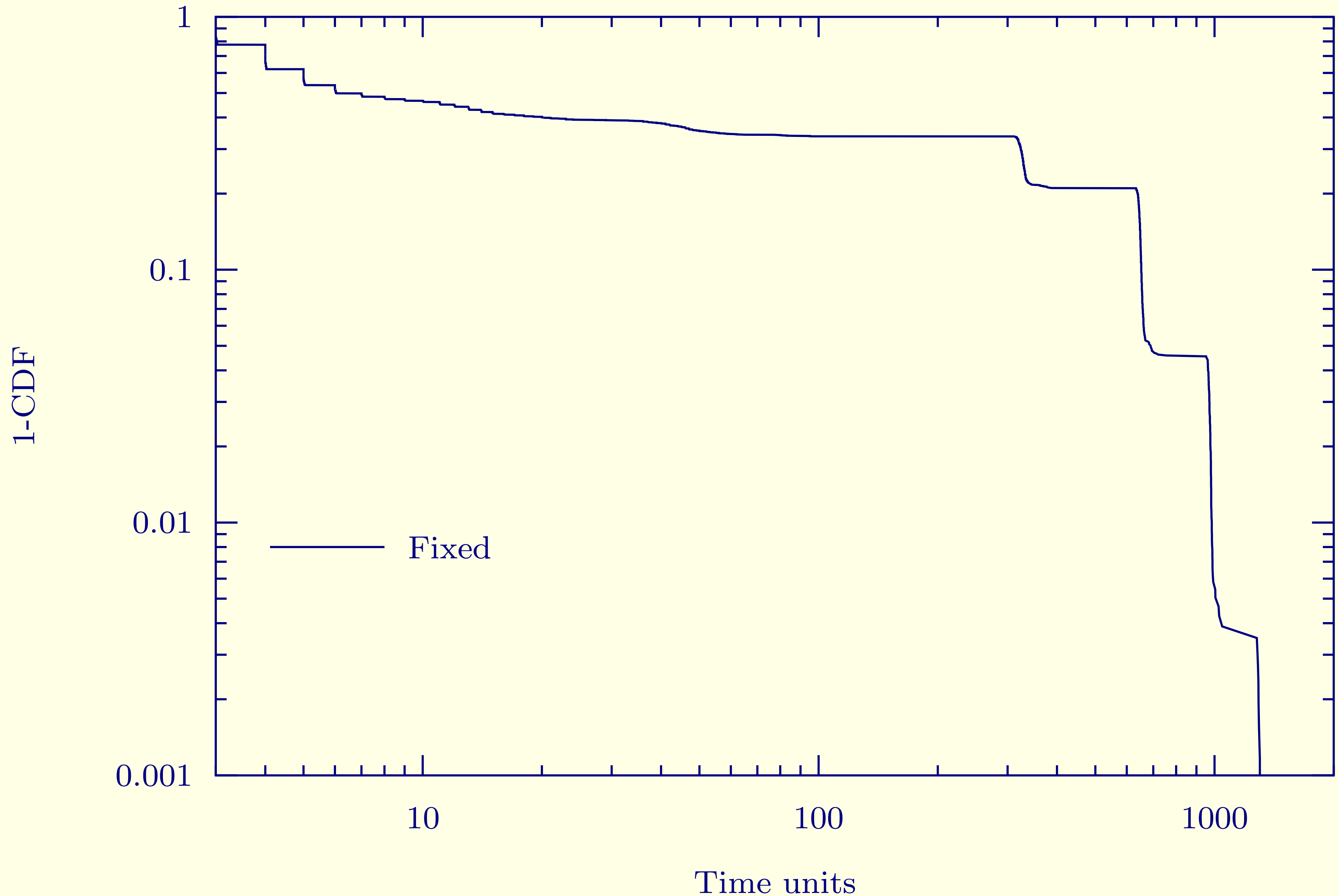


The effect of the communication network load

- Different traffic conditions modeled by different delay distributions

- Random delays impact algorithms performance in different ways:
  - **ABT:** Fixed delays better than random delays.
    The greater the variance of the delays,
    the worse the performance of ABT
  - **ABT with restarting:**
    Fairly robust to the variance of the delays
  - **AWC:** Random delays better than fixed delays.
    Extremely robust to the variance of the delays

Cumulative density functions of time to solve a hard instance (ABT)



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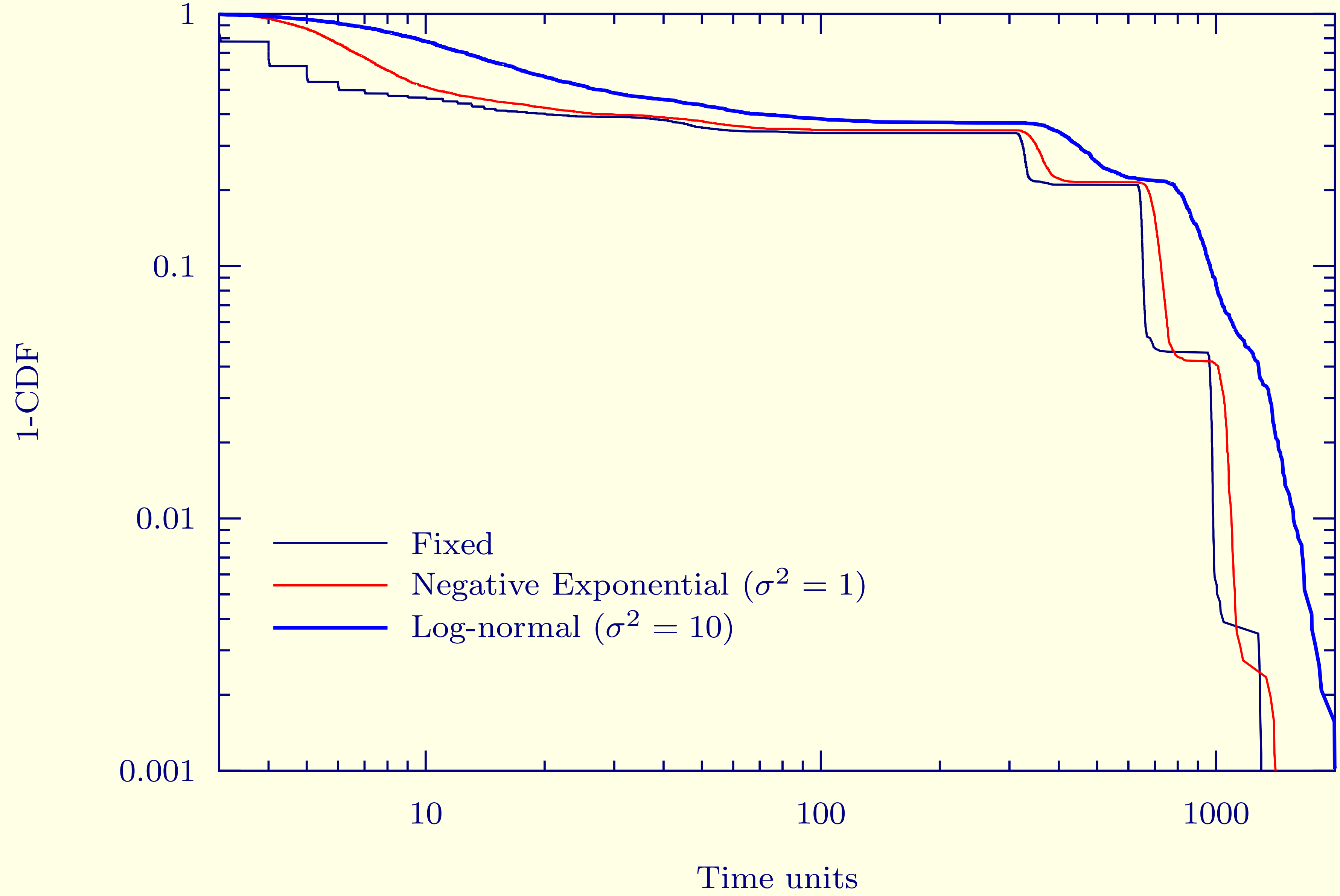

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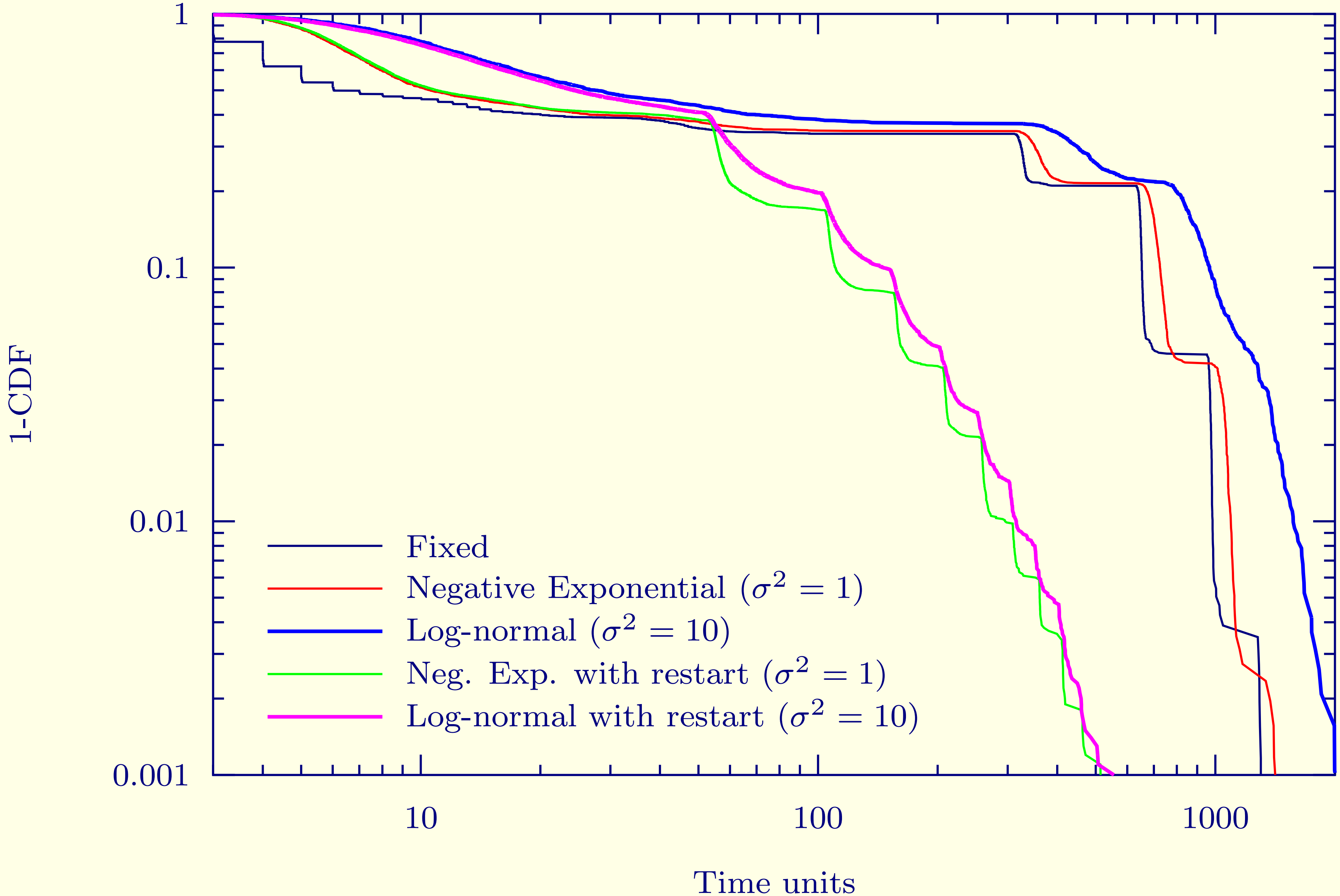
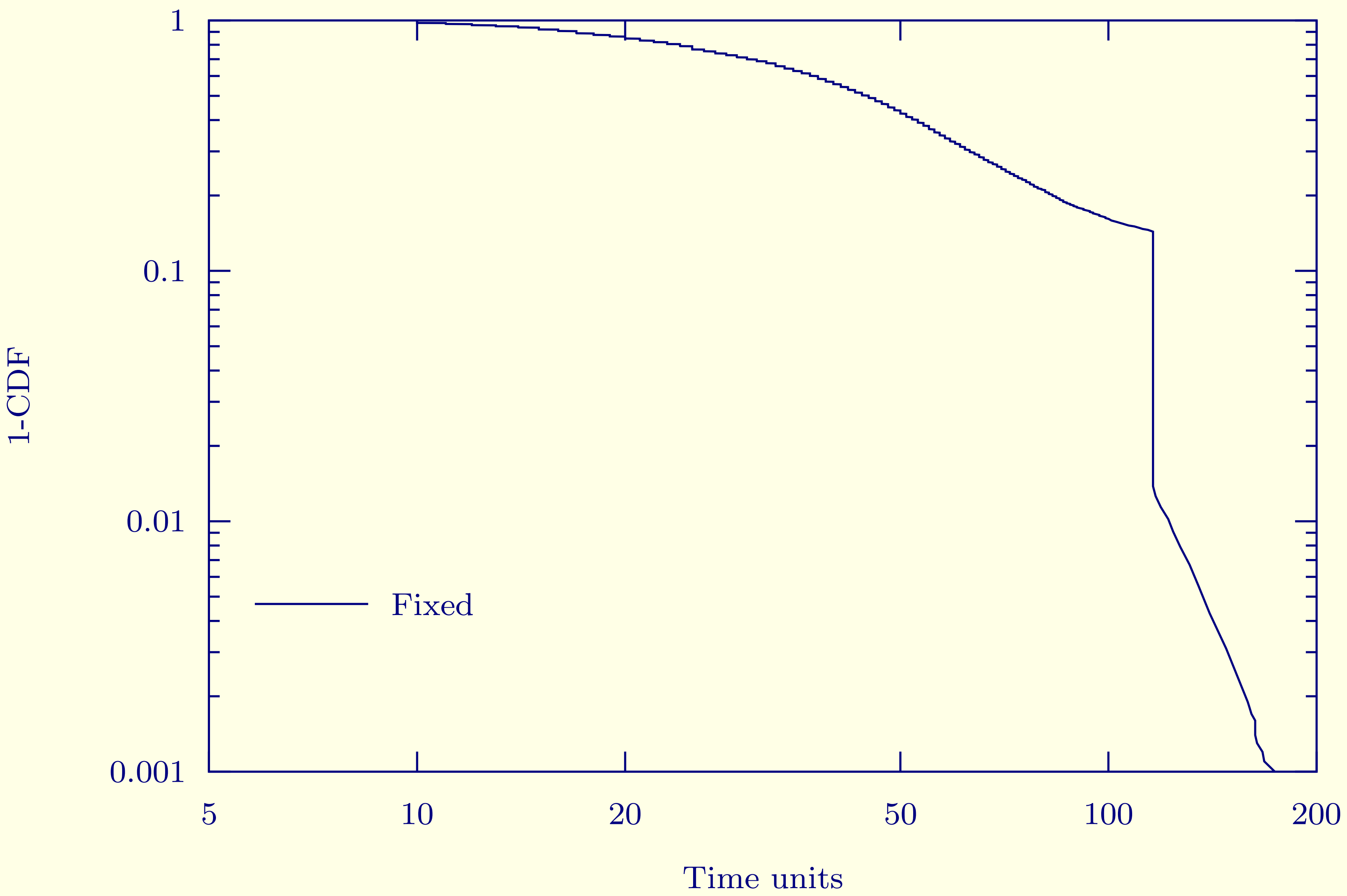


Cumulative density functions of time to solve a hard instance (AWC)



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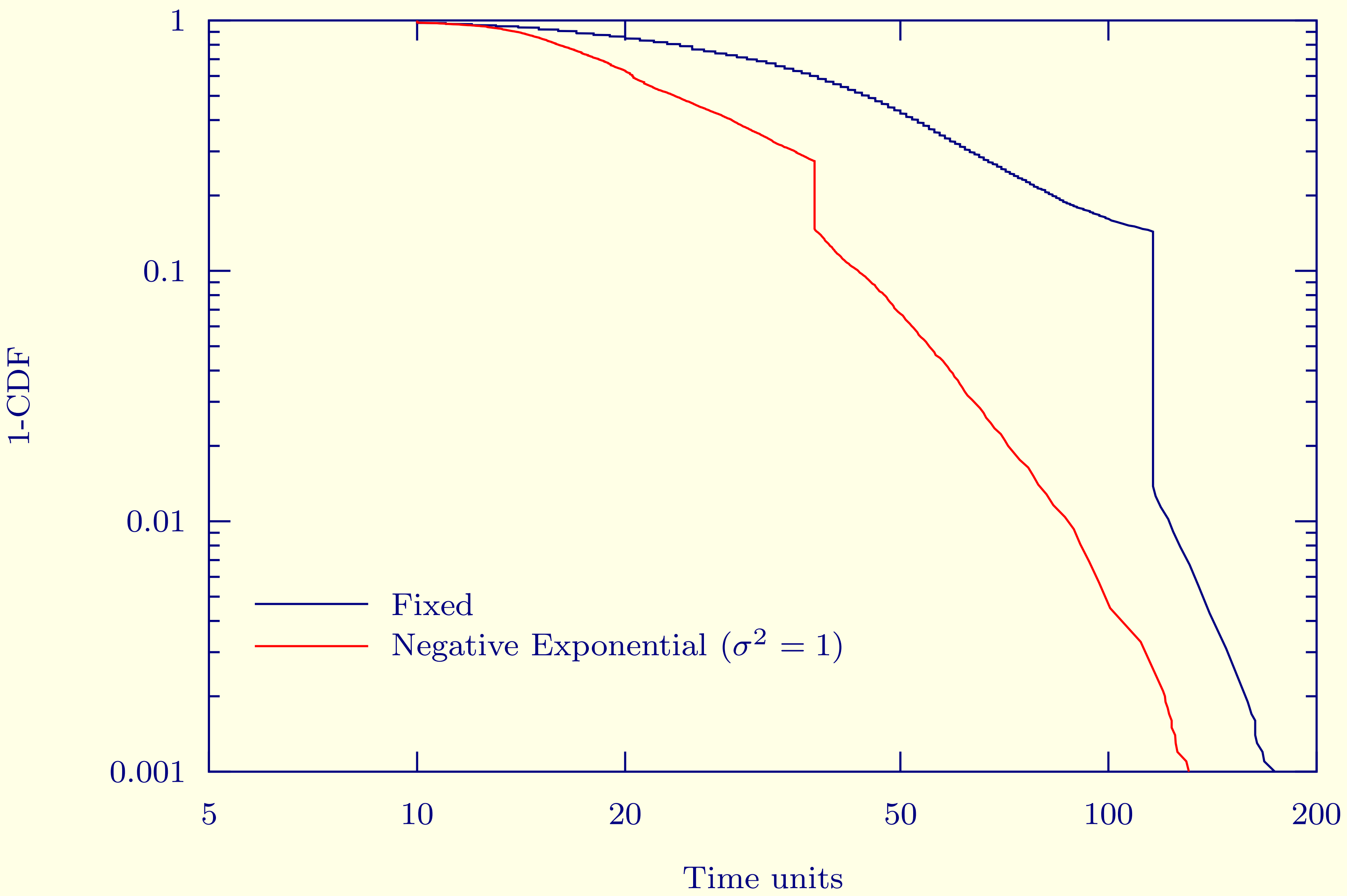

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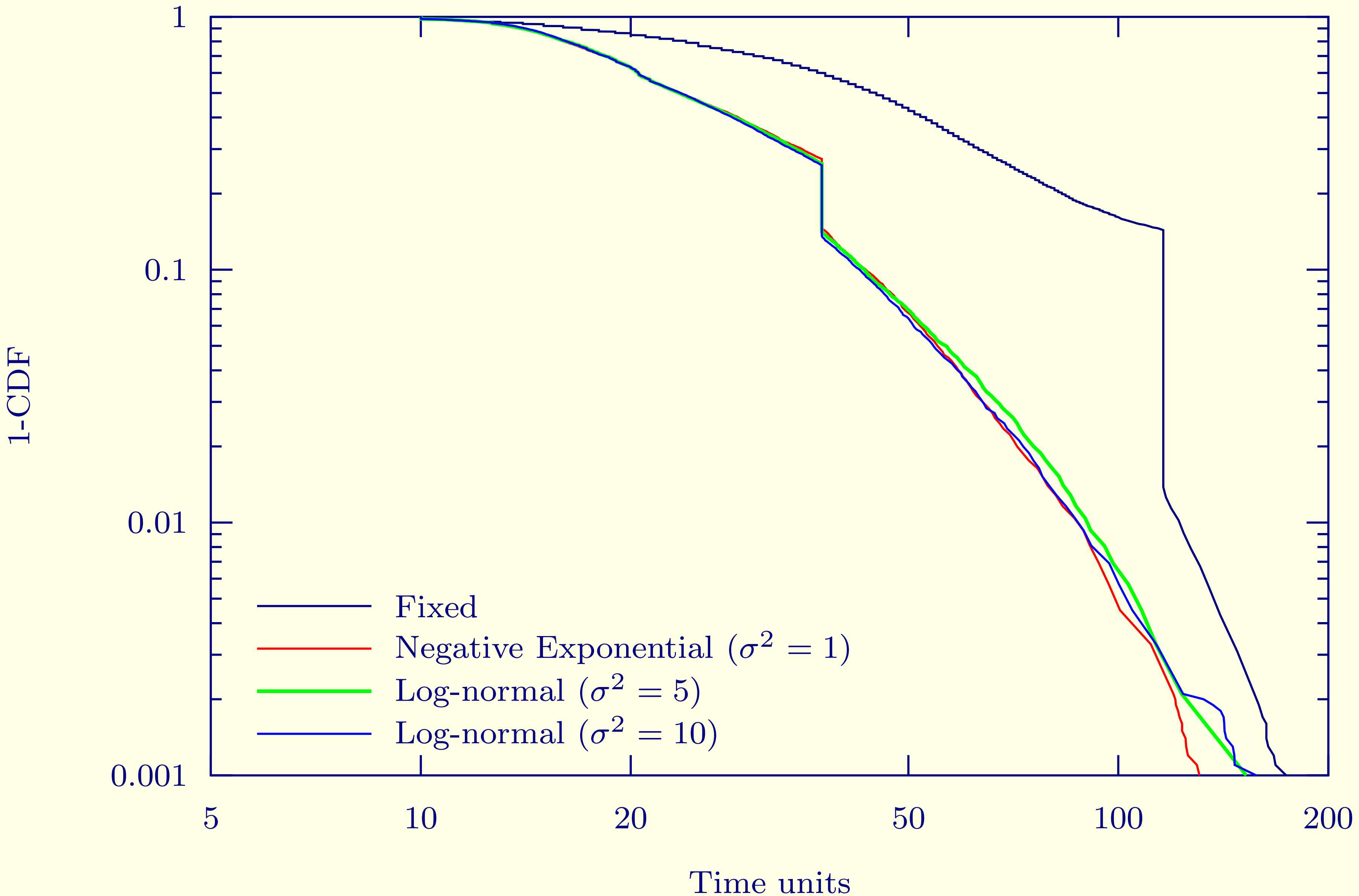

Conclusions

- Introduction of the SensorDCSP benchmark. Phase transition behavior in satisfiability. Constrainedness adjusted by the visibility and compatibility graphs
- Discrete-event simulator used to determine the impact of different network traffic conditions on the algorithms performance:
  - ABT performance worse for random delays
  - ABT improved using restarting
  - AWC performance better for random delays.
    Robustness in front of large random delay variations
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