Multiagent Distributed Watershed Management

EGU2012-821

POLITECNICO DI MILANO
Dipartimento di Elettronica e Informazione

M. Giuliani[1], **A. Castelletti**[1], F. Amigoni[1], X. Cai[2]

(1) Dept. Electronics and Information, Politecnico di Milano, Italy
(2) Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois, USA

PROBLEM FORMULATION

Generally, water resources problems are formulated as *k*-objective optimization problems and are solved in a centralized way that requires a *cooperative framework*.

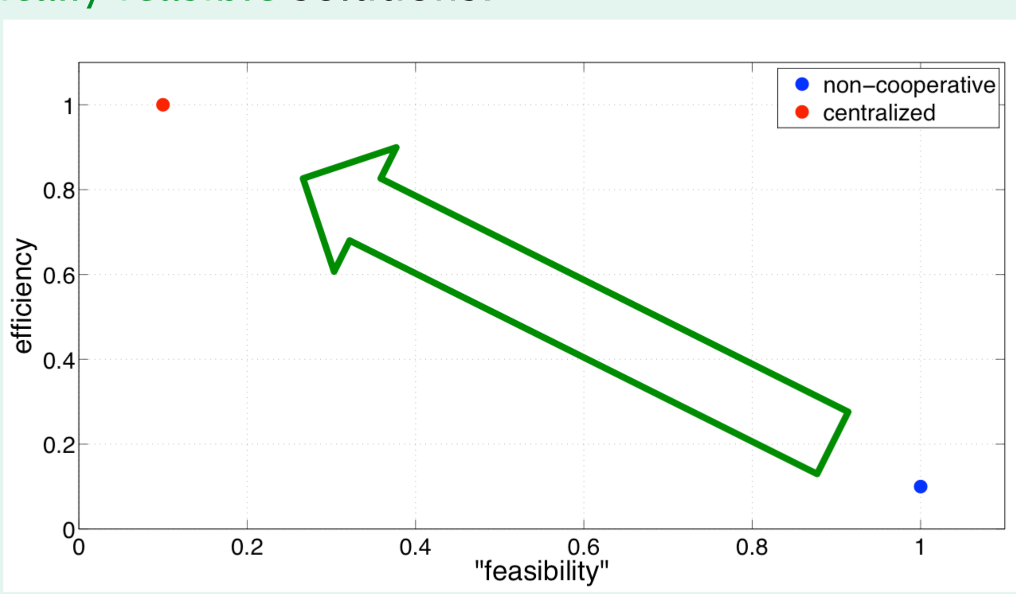
$$\max_{\mathbf{x}} \mathbf{f}(\mathbf{x}) = (f_1(\mathbf{x}), f_2(\mathbf{x}), \ldots, f_k(\mathbf{x})) \quad \text{s.t.} \quad c_1(\mathbf{x}), c_2(\mathbf{x}), \ldots, c_r(\mathbf{x}) \leq 0$$
$$\mathbf{x} \in \mathcal{D}$$

More commonly, each Decision Maker (DM) acts independently considering *his objective only* and produces sub-optimal boundary conditions for the others.

KEY IDEA OF MULTIAGENT MANAGEMENT

Multi-Agent Systems [Wooldridge, 2009] naturally allow to represent a set of self-interested agents (DMs and/or stakeholders) acting in a *distributed decision process* at the agent level.

In order to coordinate multiple and independent DMs, the *watershed authority* develops a **mechanism design** strategy: starting from the inefficient situation of independent DMs, the imposition of normative constraints on the agents' decisions drives towards more efficient and politically feasible solutions.



Agent-based methods like ***Distributed Constraint Satisfaction Problems*** (DCSP) and ***Distributed Constraint Optimization Problems*** (DCOP) solve the problem and guarantee global solution quality operating efficiently using only local communicaton.

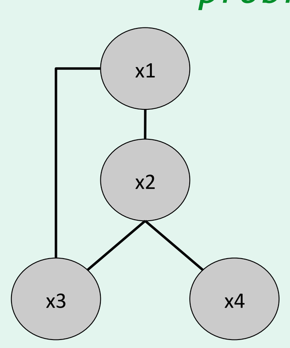
DCSP/DCOP FORMULATION

- variables $\mathbf{x} = [x_1, x_2, \ldots, x_n]$ each assigned to an agent
- finite, discrete domains $D_1, D_2, \ldots, D_n$
- a set of valued constraints over the values of x_i in $\mathbf{x}$

DCOP *finds a complete assignement minimizing a weighted sum of constraints violations.*

$$\mathbf{x} = \arg\min_{\mathbf{x}} \sum f_{i,j}(x_i, x_j) \longrightarrow$$ *optimization problem*

x_i x_j	$f(x_i, x_j)$
● ●	1
● ○	2
○ ●	2
○ ○	0



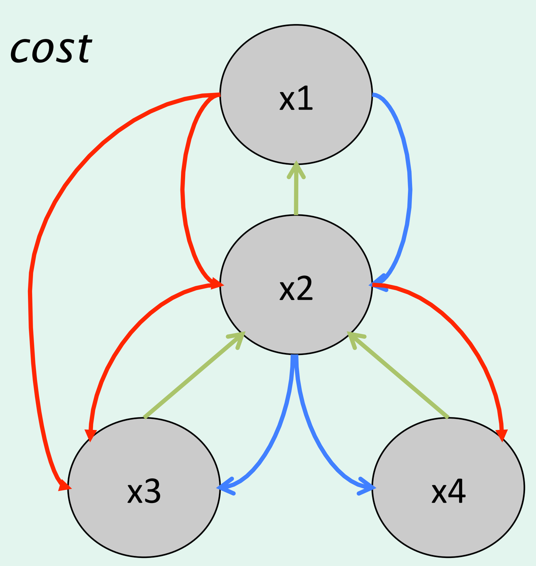
DCSP *has binary constraints* ⟶ *feasibility problem*

ADOPT ALGORITHM

- Optimal and asynchronous distributed search
- Efficient reconstruction of abandoned solutions (using backtrack thresholds)
- Built-in termination detection

Basic Algorithm:
loop until termination condition == true

- *choose value with min cost*
- *send VALUE message to descendents*
- *send COST message to parent*
- *send THRESHOLD message to child*



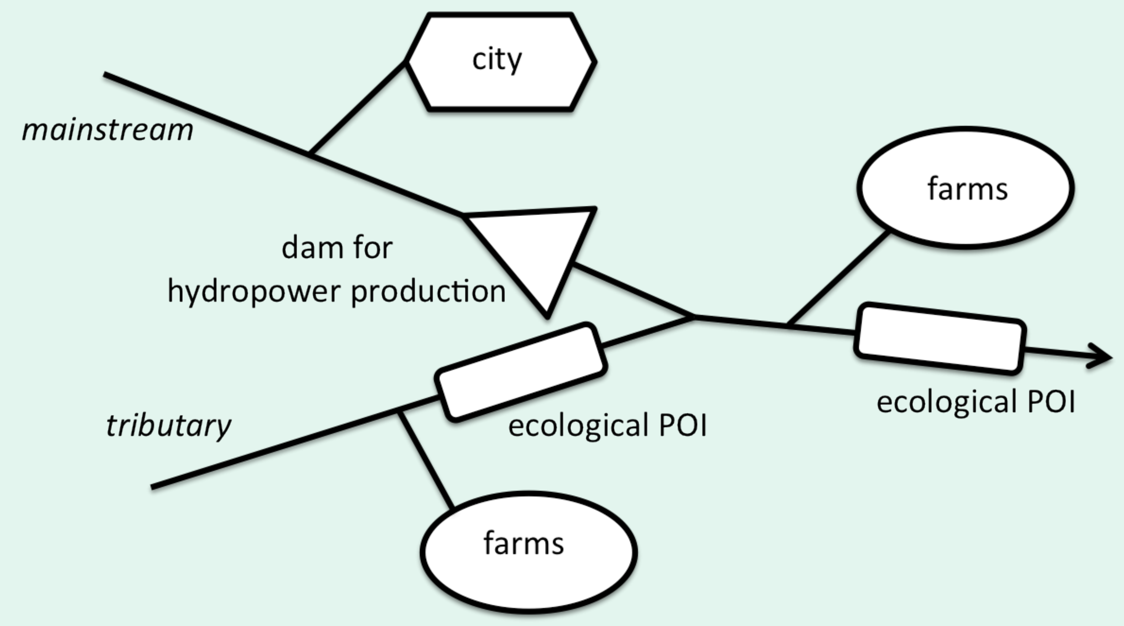
For further details see Modi *et al.* [2005].

CASE STUDY: application of DCSP-DCOP based approaches to a steady state hypothetical watershed management problem [Yang *et al.*, 2009].

MODEL

4 active human agents
(i.e. agents who make decisions)

2 reactive ecological agents
(i.e. agents representing environmental interests)



Agent Objective Function

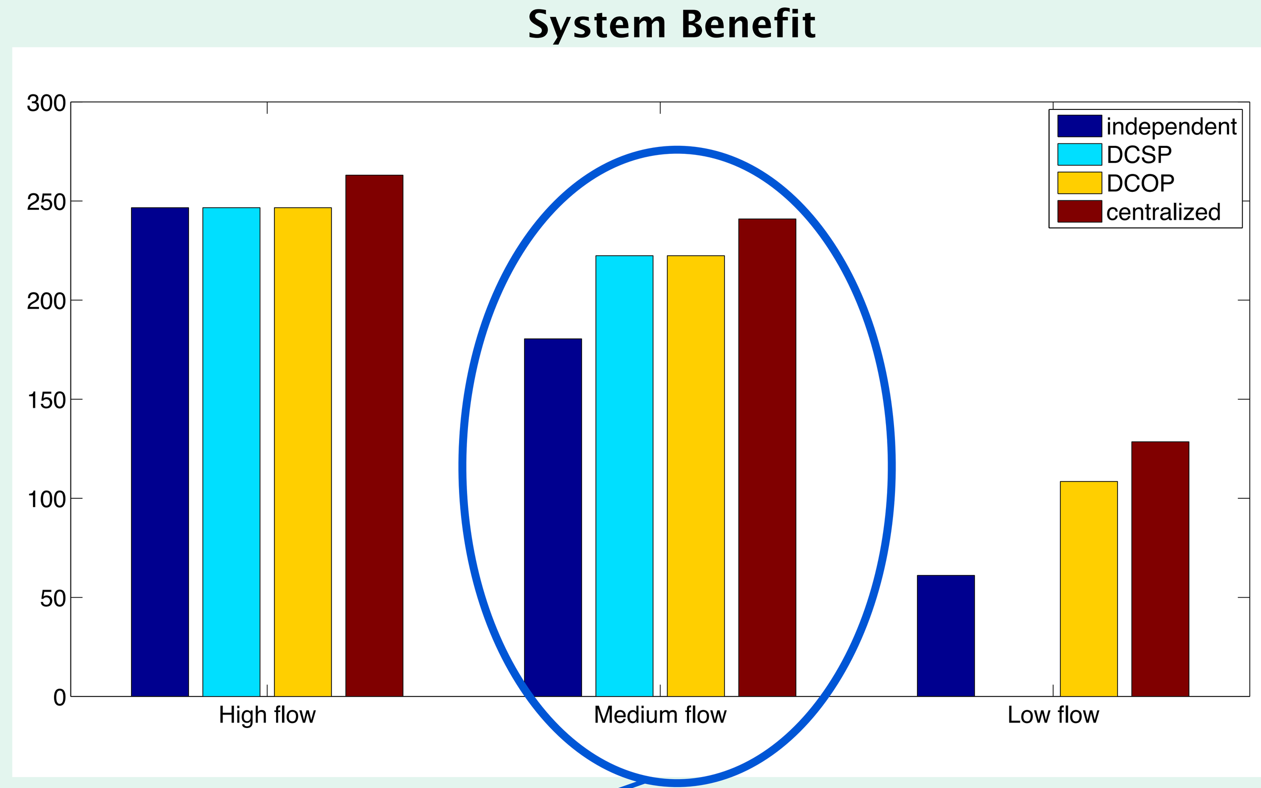
$f_i(x_i) = a x_i^2 + b x_i + c$

INTERACTION SCENARIOS

- ideal **centralized** solution which explicitly considers the ecological objectives;
- **independent** solution where each active agent acts considering his objective only;
- **DCSP**-based solution where the agents try to maximize their objective functions, but the assignment of decision variables values has to be feasible;
- **DCOP**-based solution where the agents decisions can violate the normative constraints but it is guaranteed that the solution minimizes the sum of constraints violation.

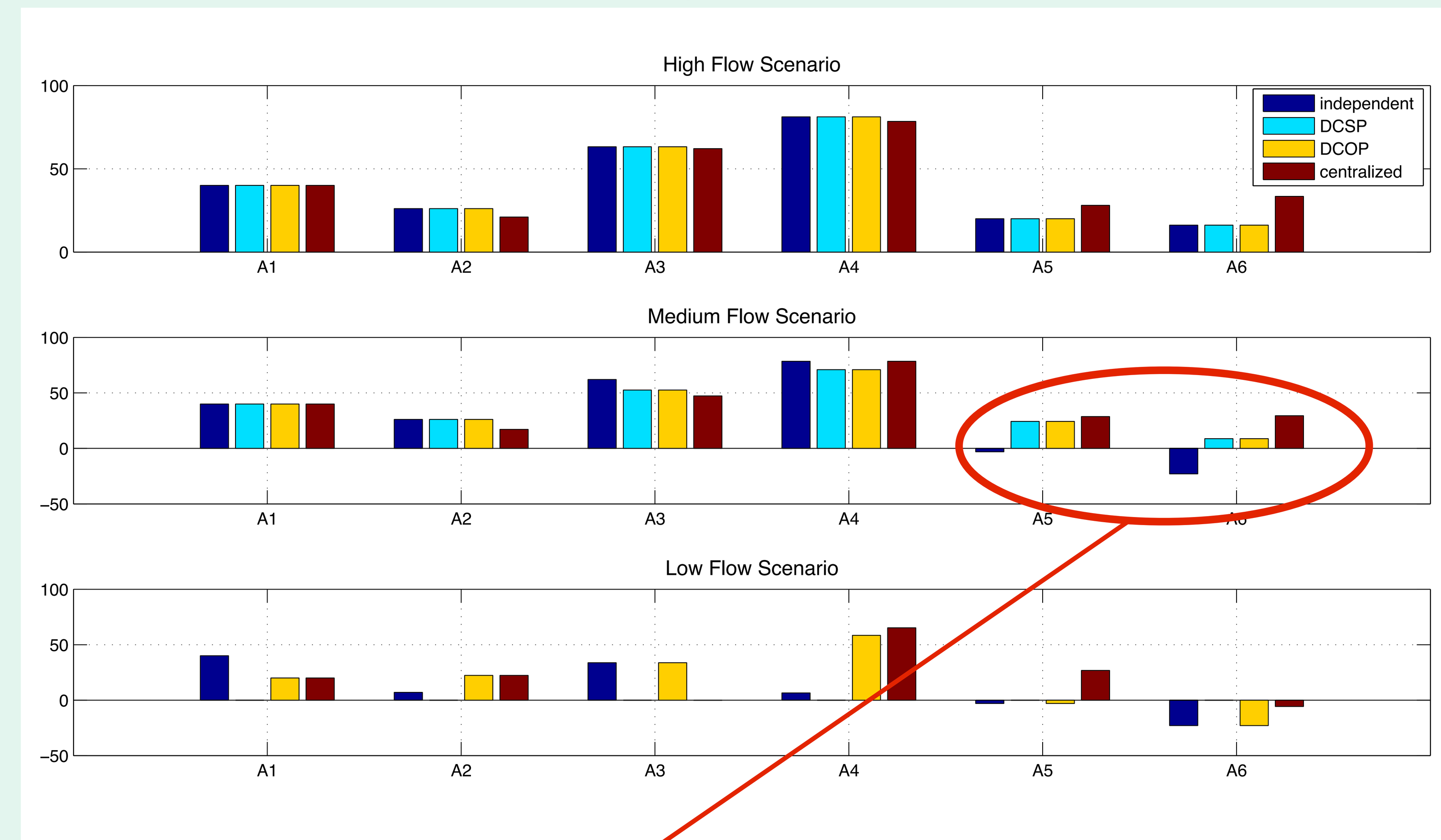
RESULTS: comparison of system and agents benefits under different interaction scenarios

System Benefit



DCSP/DCOP solutions, which are more realistic and politically feasible than the centralized one, significantly outperform the independent solution.

Agents Benefit



The imposition of normative constraints can guarantee positive benefits to the reactive ecological agents.

For details see Giuliani et al. [2012].

FURTHER RESEARCH

- Analysis of proposed algorithm's computational requirements (e.g., measuring the number of exchanged messages).
- Analysis of the scalability of the method with a increasing number of agents.
- Extension of the method to deal with dynamic water systems: development of a DCOP Model Predictive Control scheme.
- Application of the DCOP-MPC to a real-world case study.

REFERENCES

- M. Giuliani, A. Castelletti, F. Amigoni and X. Cai (2012). Multi-Agent Systems optimization for distributed watershed management. Submitted to *6th International Congress on Modelling and Simulation*, July 1-5, Leipzig (Germany).
- P. Modi, W. Schen, M. Tambe and M. Yokoo (2005). Adopt: asynchronous distributed constraint optimization with quality guarantees. *Artificial Intelligence*, 161(1-2):149-180.
- M. Wooldridge (2009). *An Introduction to MultiAgent Systems*, Second Edition. Wiley, NY.
- Y.C.E. Yang, X. Cai, and D.M. Stipanović (2009). A decentralized optimization algorithm for multiagent system-based watershed management. *Water Resour. Res.*, 45(W08430).

Contact: Matteo Giuliani
giuliani@elet.polimi.it