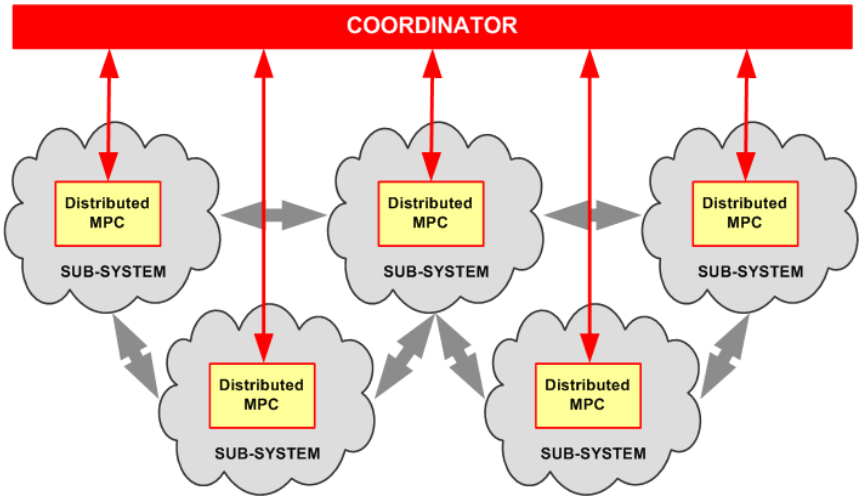
WIDE End-User Panel Meeting
WP3: Distributed MPC

Honeywell Prague Laboratory

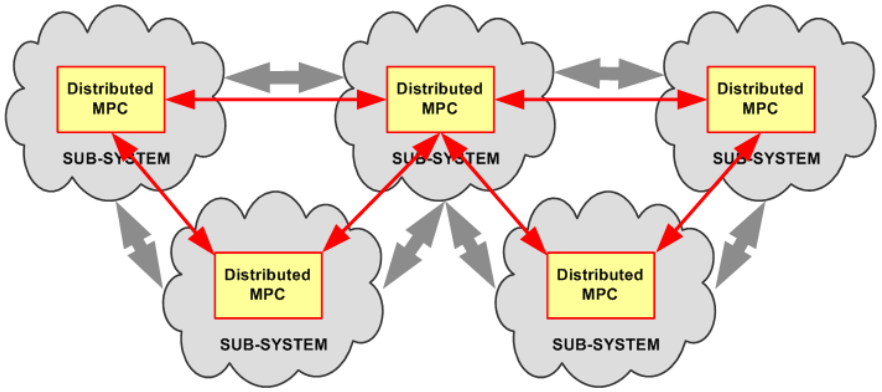
Honeywell

Distributed MPC for large-scale systems

- The complexity of MPC increases quickly with system size (~$O(n^3)$)
- Application of MPC to large-scale systems requires distributed or decentralized solution
- Our effort was directed to distributed MPC:
  - \+ Minimum performance degradation to centralized MPC
  - \- Requires consensus iterations in each sampling period (more then one information exchange in each sampling period for every distributed MPC)
- Target systems with 10x seconds sampling period and hundreds of MV's



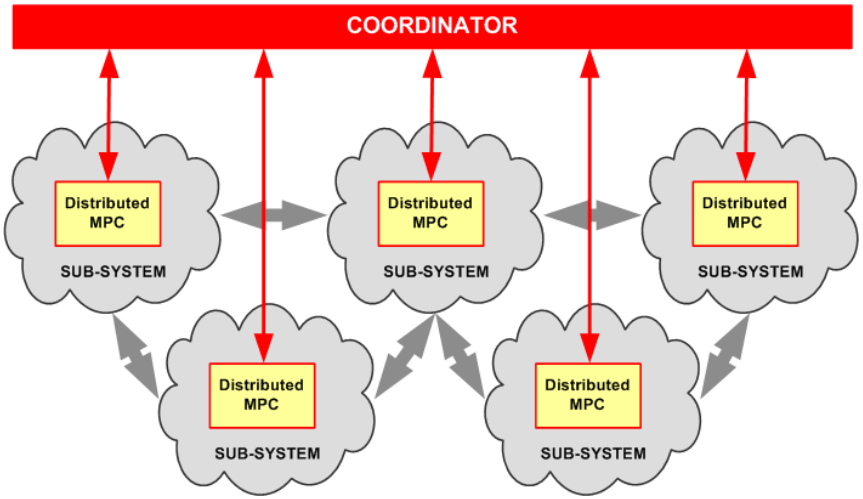
Distributed MPC **with** central coordination



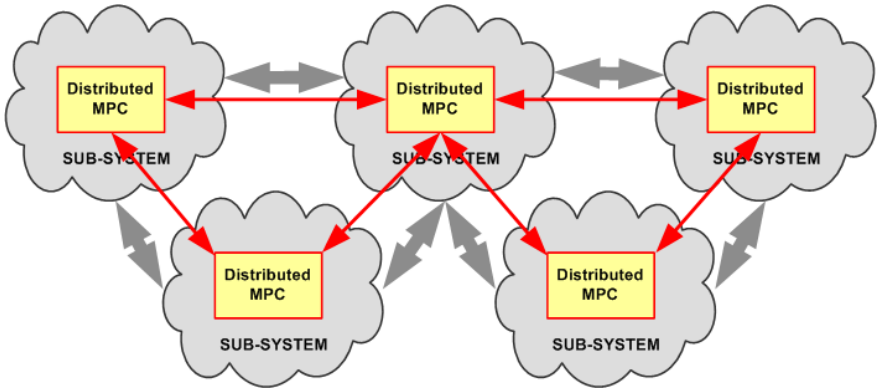
Distributed MPC **without** central coordination

Distributed MPC for large-scale systems

- Our solutions are based on a well known dual decomposition of optimization problems
- Original problem is distributed to multiple optimization problems, which are iteratively coordinated together until consensus is reached (price coordination)
- Efficient coordination algorithm is crucial
- Coordination algorithm types:
  - Centralized coordination: Novel algorithm with Parametric coordination
  - Distributed coordination: Nesterov accelerated gradient method



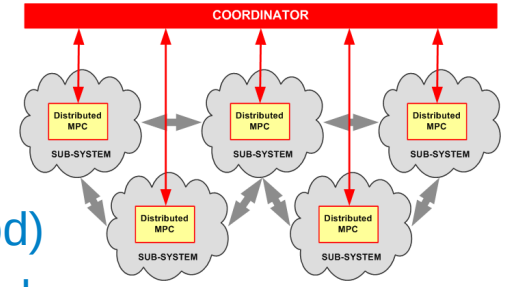
Distributed MPC **with** central coordination

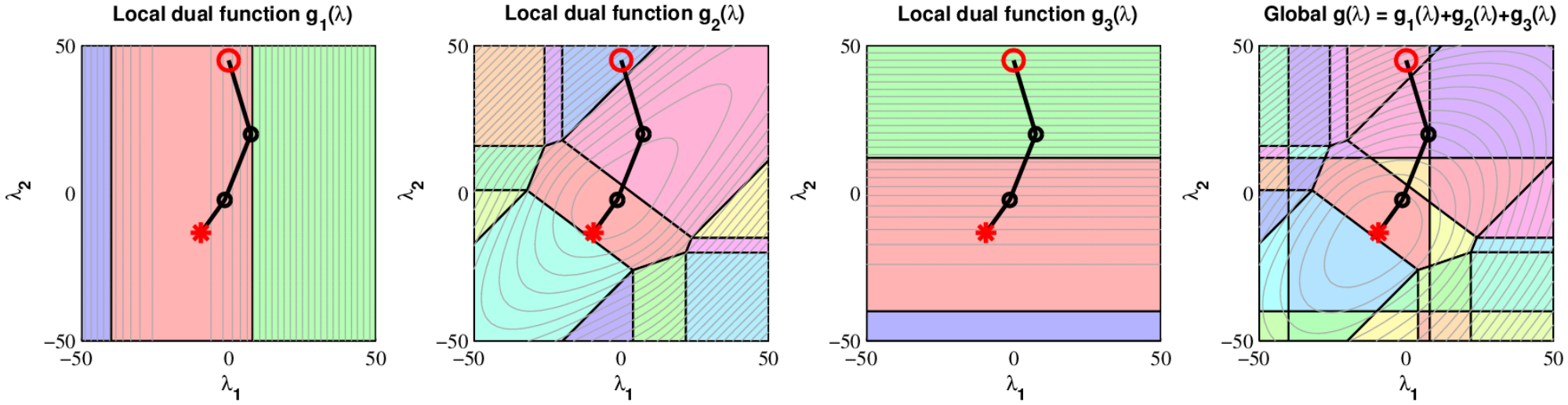


Distributed MPC **without** central coordination

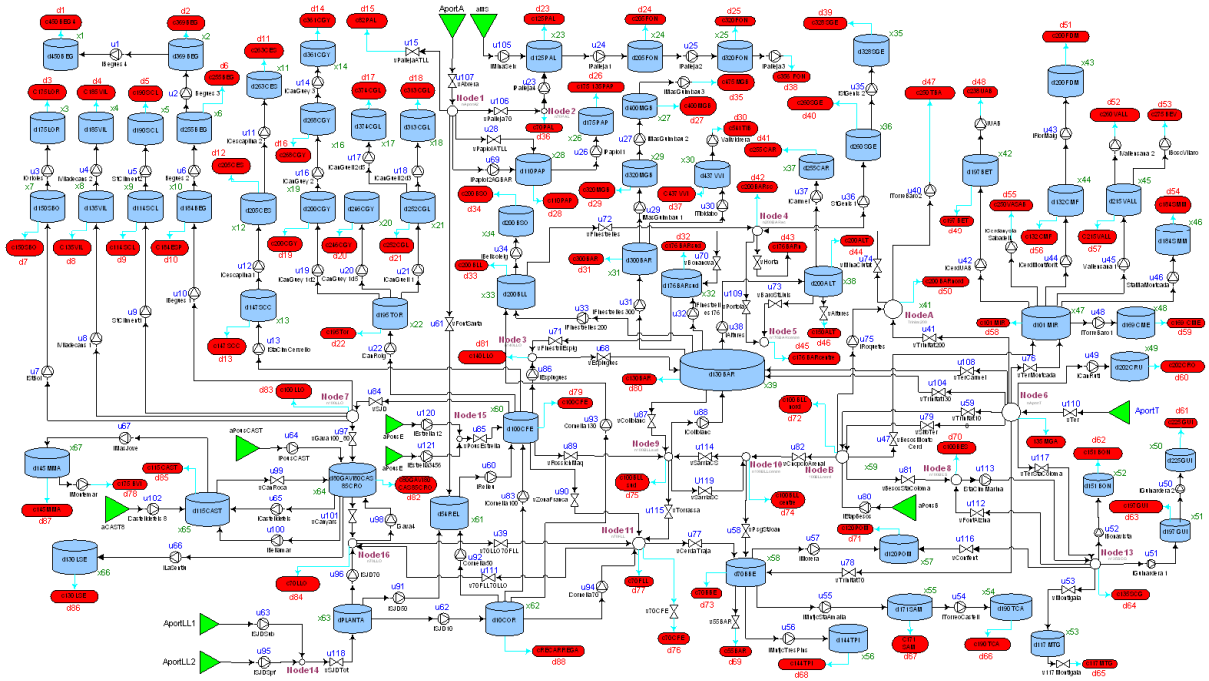
Parametric coordination

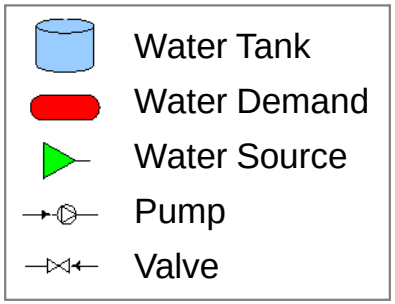
- For linear MPC only
- Properties:
  - Consensus reached in a finite number of iterations
  - Fast algorithm with low number of iterations (Newton type method)
  - Each iteration require only some local problems to be recomputed
  - Consensus can be reached in a single iteration for warm start
- Coordination is based on multi-parametric programming
- Local optimizers (local MPC's) compute and return their solution in a requested point and its polytopic neighborhood
- Only required polytopes are computed (explicit solution of local MPC problems is too big)





Parametric Coordination: Results on Barcelona Network





Overview:

- 70 tanks
- 15 main water nodes,
- 110 pumps/valves
- 80 demands (disturbances)
- 9 water sources

Control Objectives:

- fulfill demands - tank levels above safety level on prediction horizon
- minimize prices for:
  - fresh water
  - pumping (time varying electricity price)
- minimize MV changes, minimize tank levels
- constraints (pumps, valves, tanks, water sources)

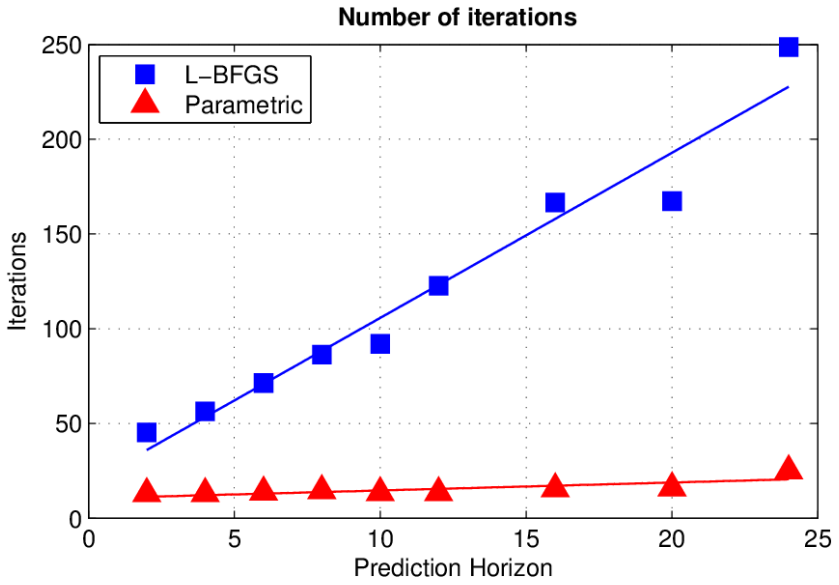
MPC Optimization Problem Size

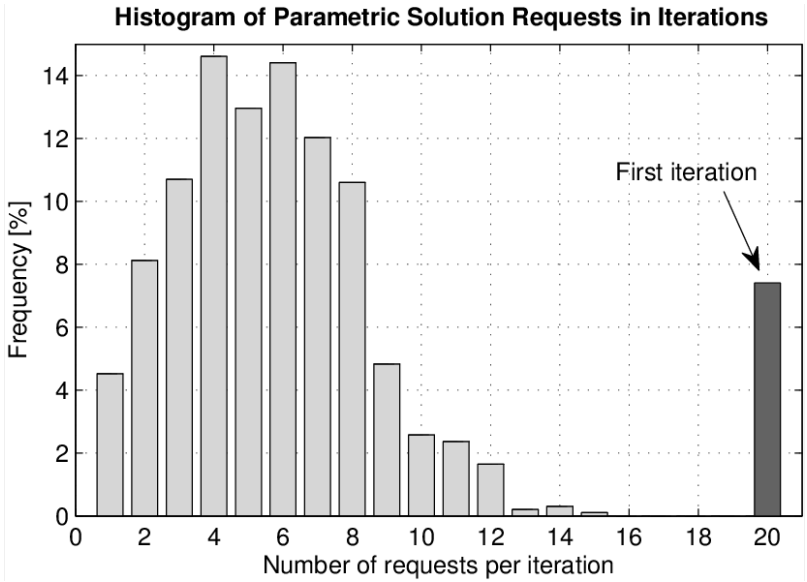
Quadratic programming problem imposed by MPC:
(~120 MV's, ~80 DV's, ~70 CV's)

Prediction horizon	24 hours
Sampling period	1 hour
Number of variables	~5.000
Number of constraints	~10.000

Parametric Coordination: Results on Barcelona Network

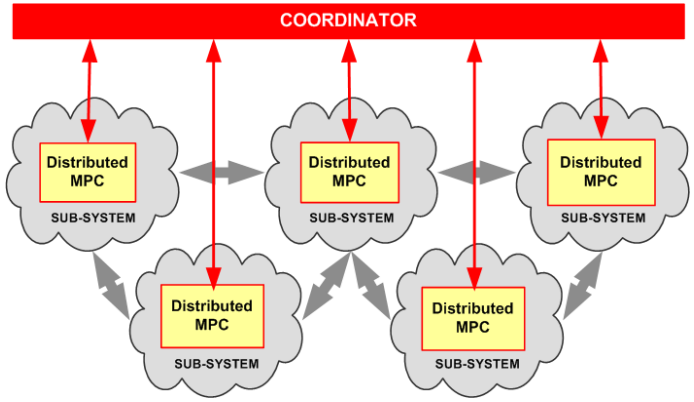
- Network was separated to 20 groups
- Each group has local MPC controller
- Same result with centralized MPC up to ~0.1% consensus error threshold
- Compared methods
  - Centralized MPC
  - Distributed MPC with L-BFGS coordination
  - Distributed MPC with Parametric coordination
- Results:
  - ~10x reduction in a number of iterations (compared to quasi-Newton L-BFGS)
  - Only ~25% of local problems are recomputed in each iteration
  - ~100x faster than centralized MPC and ~10x faster than L-BFGS



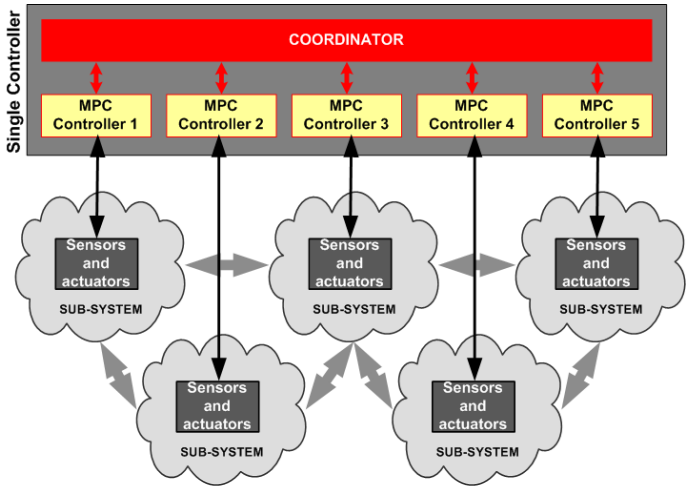


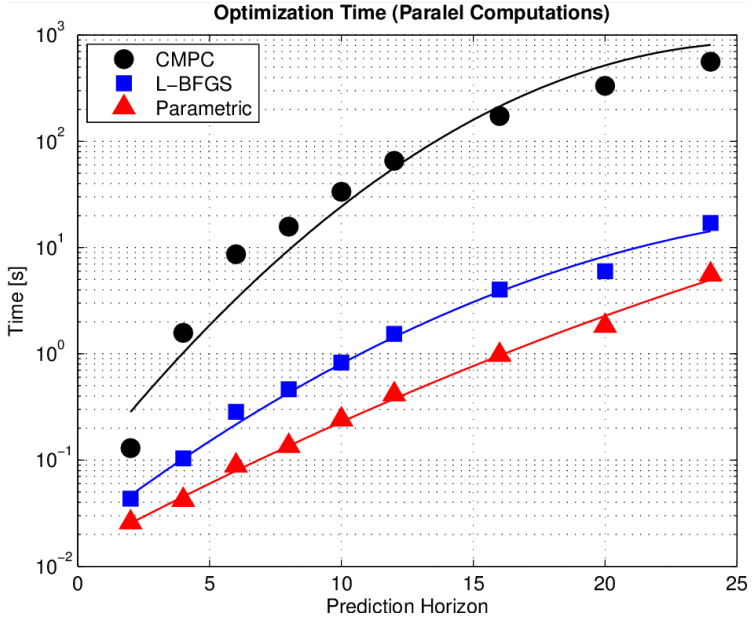
Parametric Coordination: Results on Barcelona Network

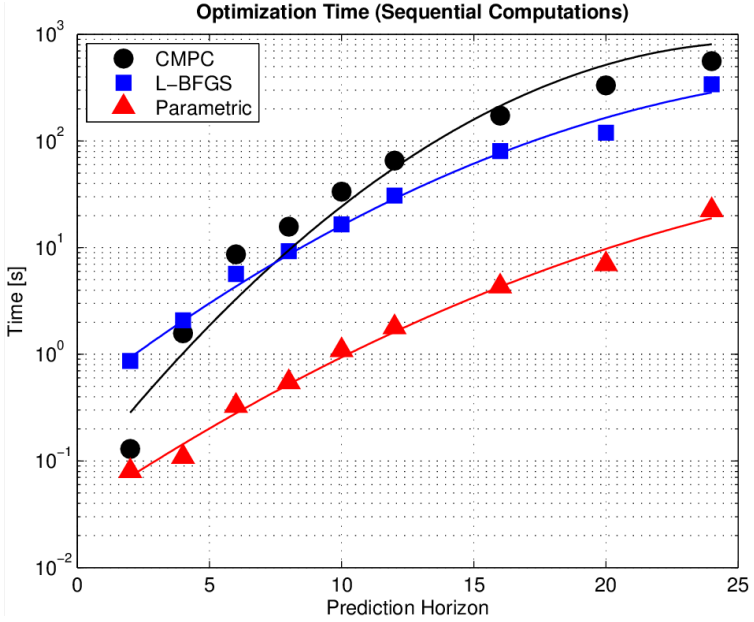
Parallel computations (multiple controllers)



Sequential computations (single controller)





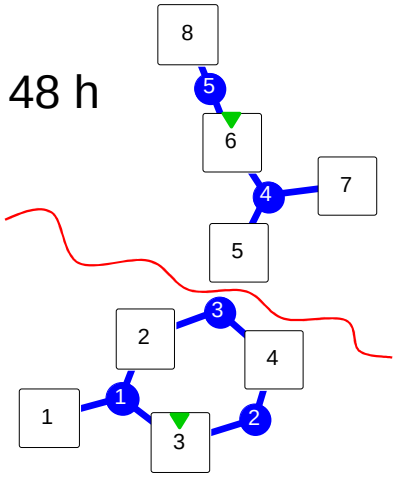


Distributed coordination: Nesterov Accelerated Gradient Method

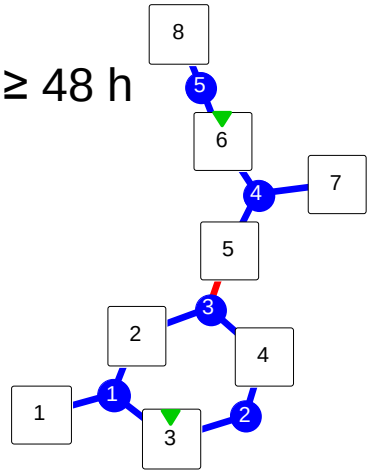
- Communication exchange with neighbors only
- Highly modular solution – changes in system configuration without global control strategy adjustment
- 100x of iterations for Barcelona network (24 hrs horizon)

Example:

t < 48 h



t ≥ 48 h



1. t<48 networks are unconnected
2. t≥48 networks are connected
3. t≥96 connecting pump is switched to MAN

Blue line – optimal control of connected networks

Green line – optimal control of unconnected networks

Red line – control of network with configuration changes

Selected Network Flows