Multi-Agent Control of Large-Scale Network Systems

Mini-symposium on Traffic Control

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Overview

1. **Large-scale networks**
2. **Unified modeling approach**
3. **Control of networks**
   - **Model predictive control**
   - **Multi-agent model predictive control**
4. **Issues to be addressed**
5. **Alternative approach**
6. **Questions**

1. Large-scale networks

Transportation networks

- Traffic networks, power distribution networks,
- Water networks, gas networks, etc.

Why transportation networks?

- Efficient operation crucial for modern economy, environment, safety, ...

Expanding infrastructure expensive.

Instead, make better use of existing infrastructure.

2. Unified modeling approach

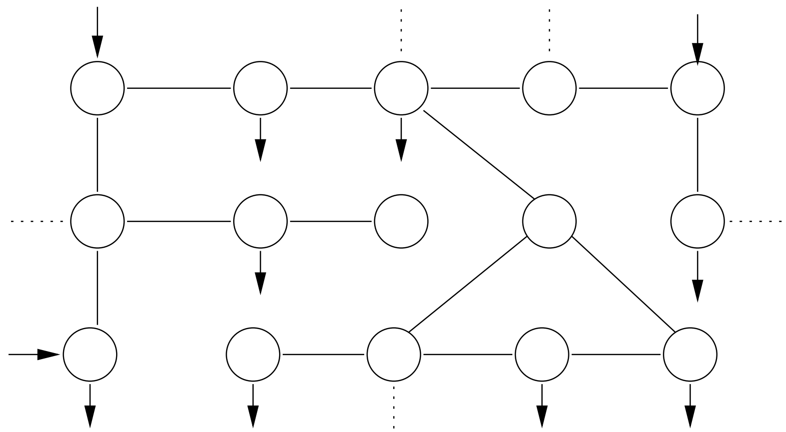
Transportation networks seen in a unified representation.
Framework applicable in many domains.

In general, in a transportation network, there is

1. *commodity*, which
2. *flows* over the network, while
3. *components* influence the flow, which is
4. restricted by *interconnections*.

2. Unified modeling approach

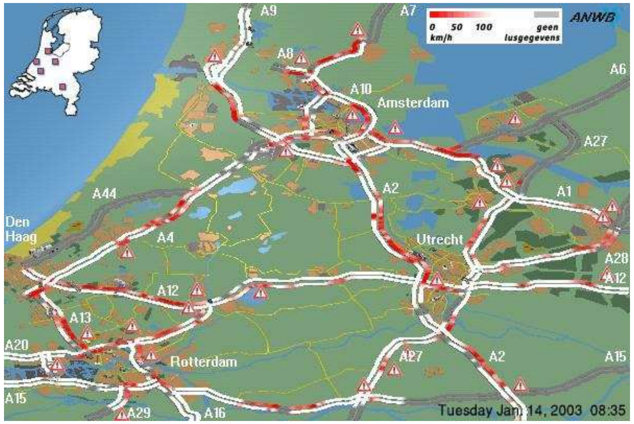
Domain	Traffic Networks	Power Distribution Networks
Commodity	vehicles	power
Sources	origins	power generators
Sinks	destinations	industrial/residential loads
Switches	traffic signals	power splitters
Intersections	cross points	busses
Interconnections	roads	power lines



3. Control of networks

Perhaps multiple, potentially conflicting, goals and operating constraints. Control goals for transportation networks:

- Efficient capacity usage
- Congestion avoidance
- High supply quality and reliability
- Domain specific goals



3. Control of networks

Formulation as dynamic optimization problem:

variables model state and controls of network,

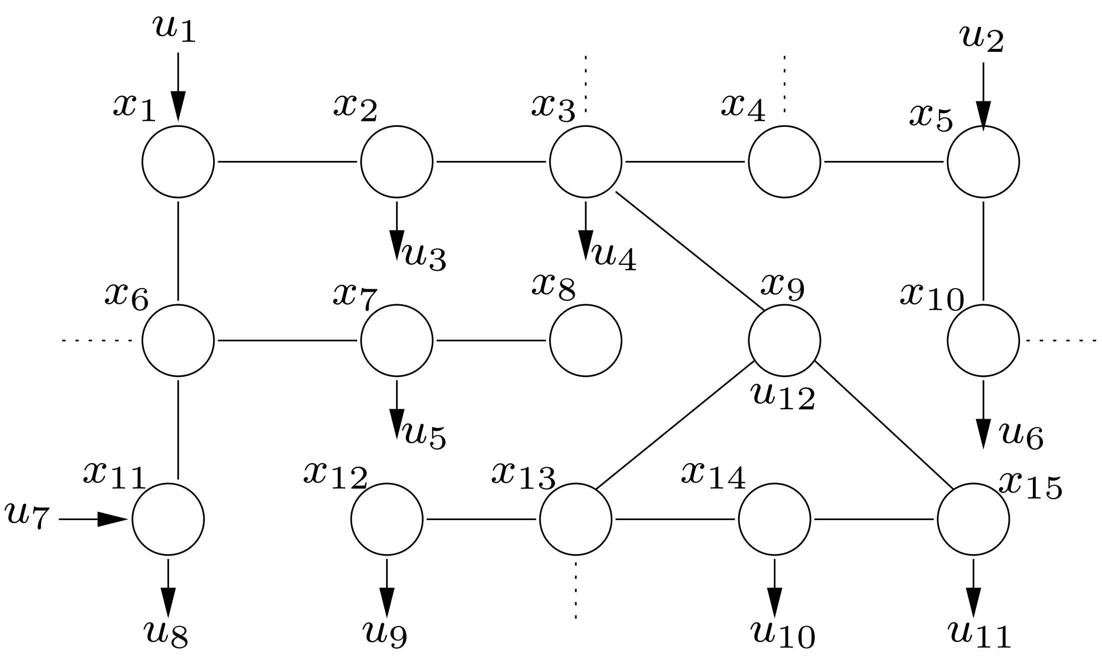
constraints model operating requirements and dynamics.

$\min_u \int_0^\infty f(x, \dot{x}, u, t)dt$

subject to

$H(x, \dot{x}, u, t) = 0$

$G(x, \dot{x}, u, t) \leq 0$.



3.1 Model predictive control (MPC)

Solution approach: model predictive control

- dynamic problem approximated with static problems.
- computation of control actions over certain horizon.

Optimization at each step:

$$\min_U f(X, U)$$

subject to

$$H(X, U) = 0$$

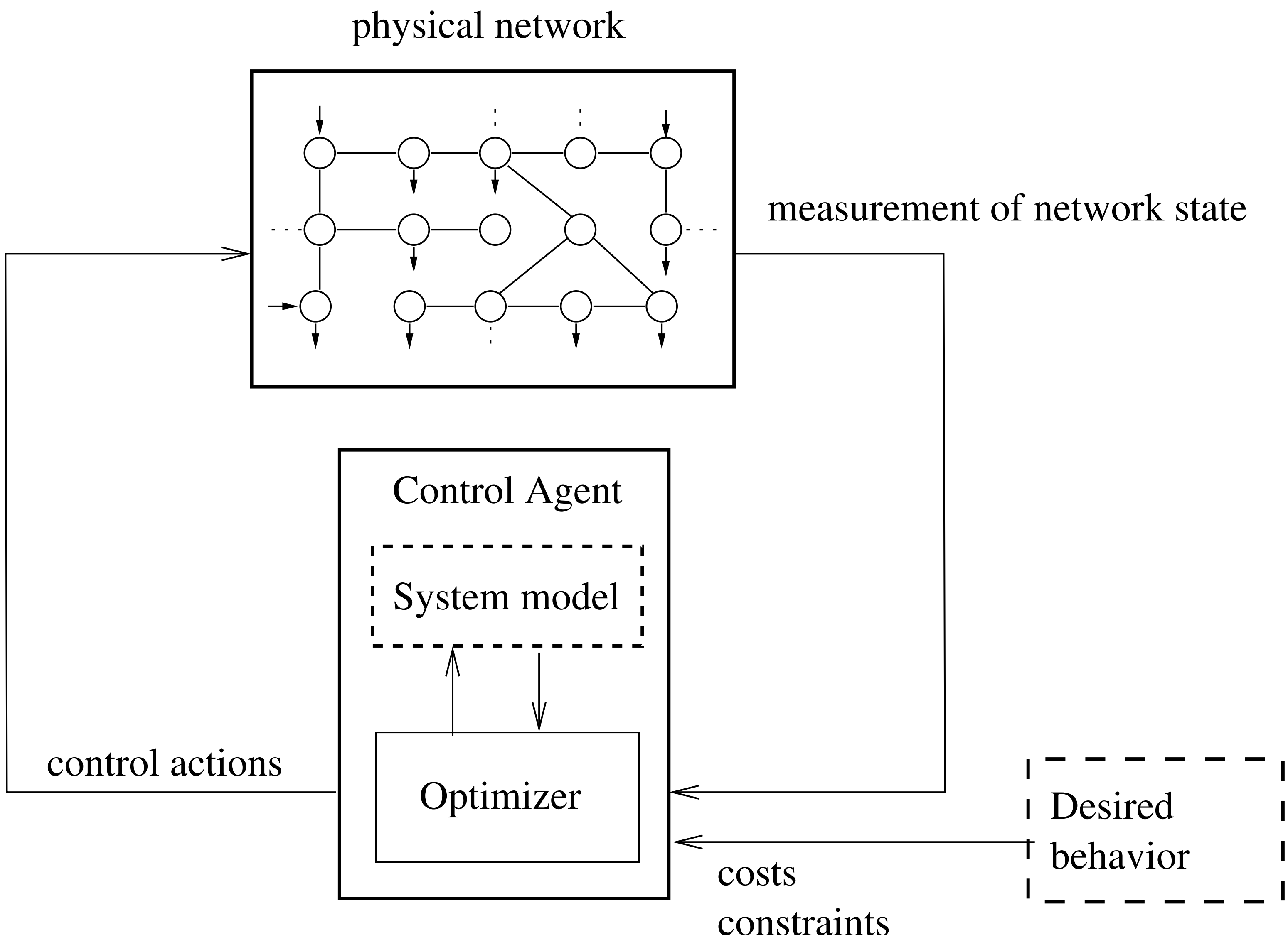
$$G(X, U) \leq 0.$$

where:

$X = [x(t_0), \ldots, x(t_N)]$: states over horizon

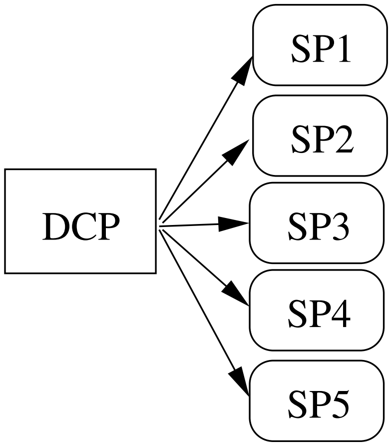
$U = [u(t_0), \ldots, u(t_N)]$: actions over horizon

3.1 Model predictive control



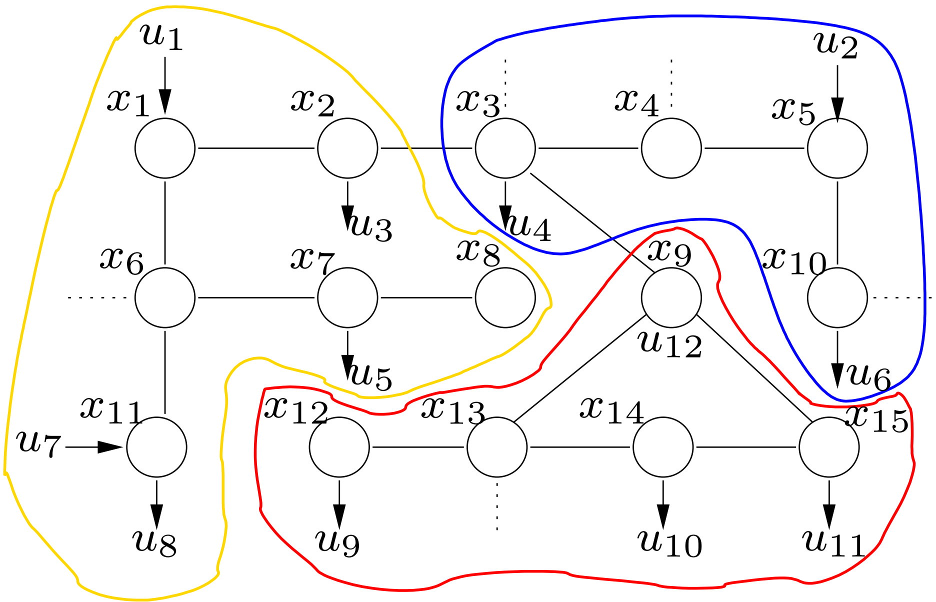
3.2 Multi-agent MPC

Static approximations can become too large.
Approach: make smaller
local approximations.



Grouping of variables into:

- local variables
- neighborhood variables
- remote variables



3.2 Multi-agent MPC

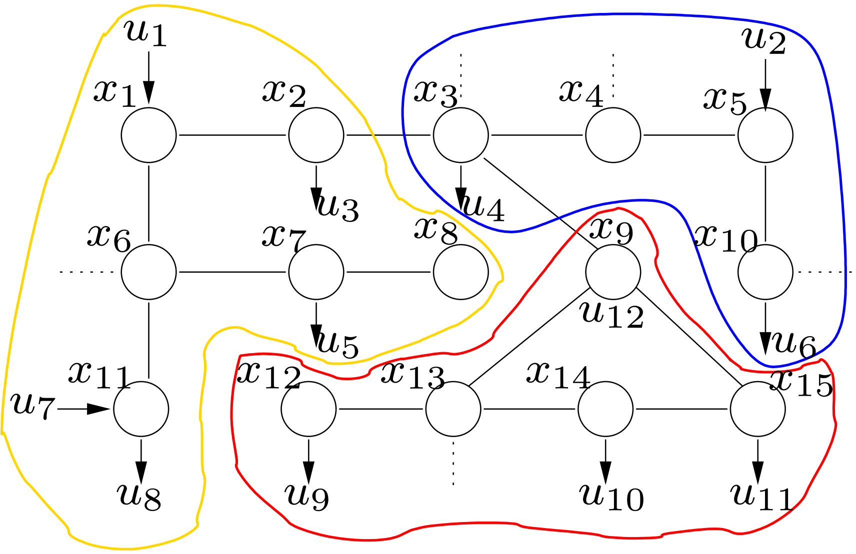
SPi: $\min_{U^i} f^i(X^i, U^i, Y^i, Z^i)$

subject to

$$H^i(X^i, U^i, Y^i, Z^i) = 0$$

$$G^i(X^i, U^i, Y^i, Z^i) \leq 0,$$

where:



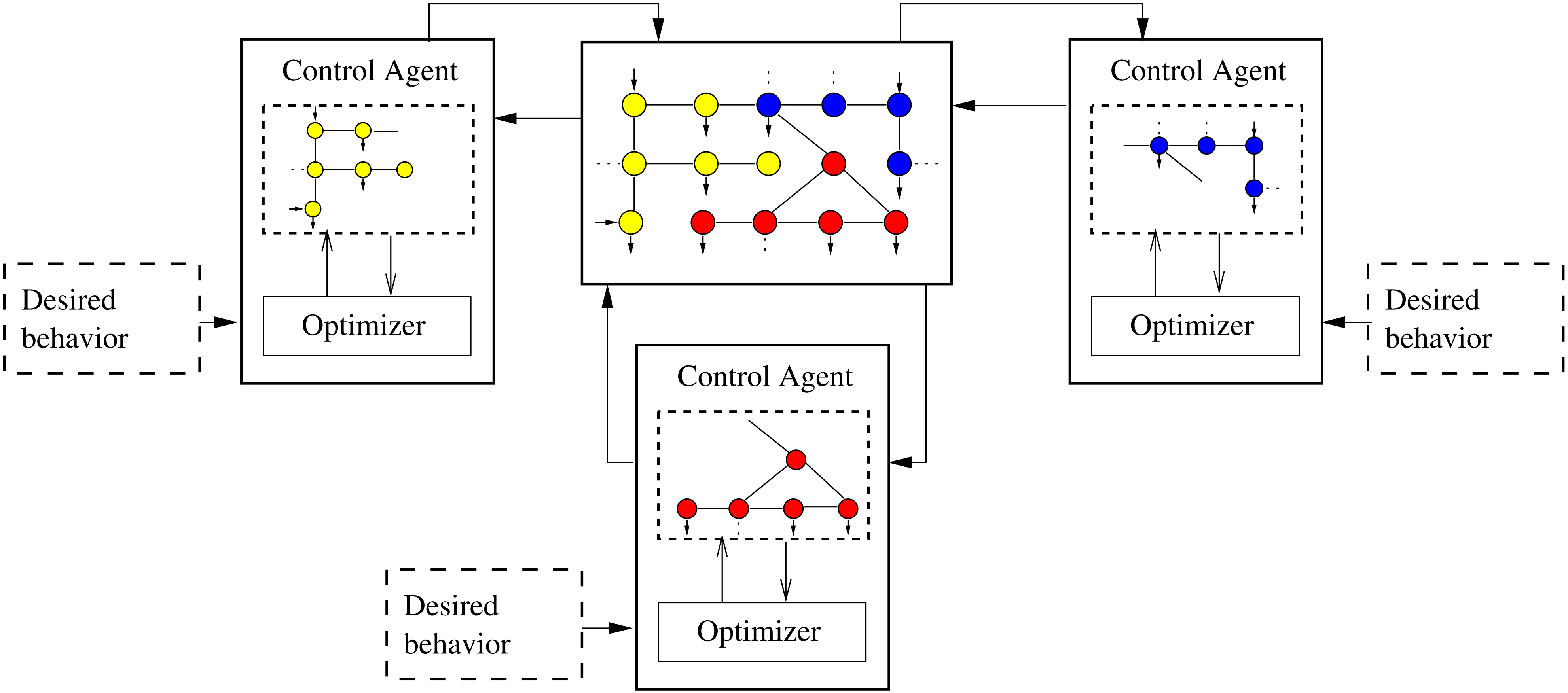
$X^i = [x^i(k), \ldots, x^i(k+N)]$

$U^i = [u^i(k), \ldots, u^i(k+N)]$

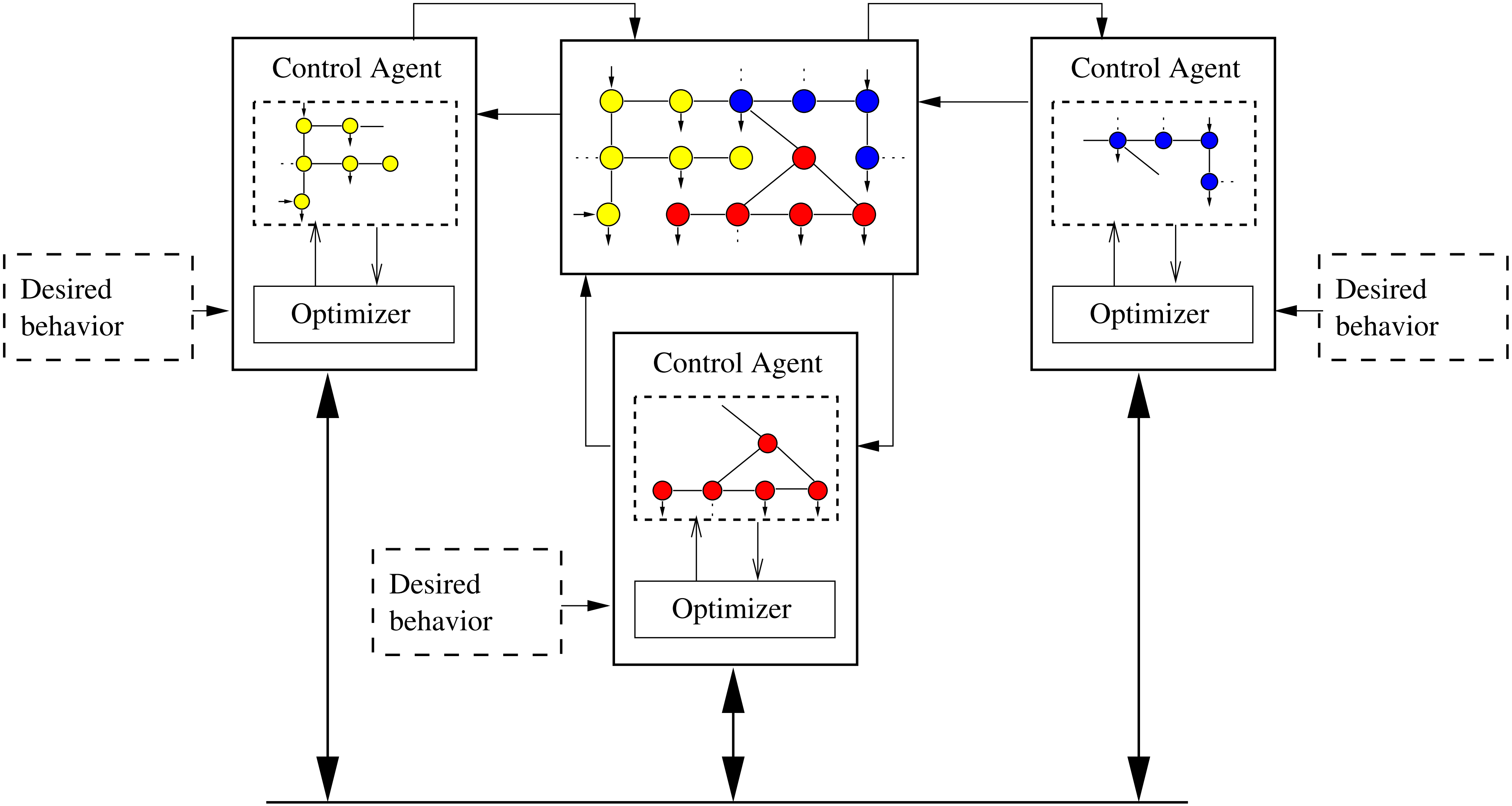
$Y^i = [X^k, U^k |$ agent k neighbor of $i]$

Z^i: components not sensable nor controllable by i.

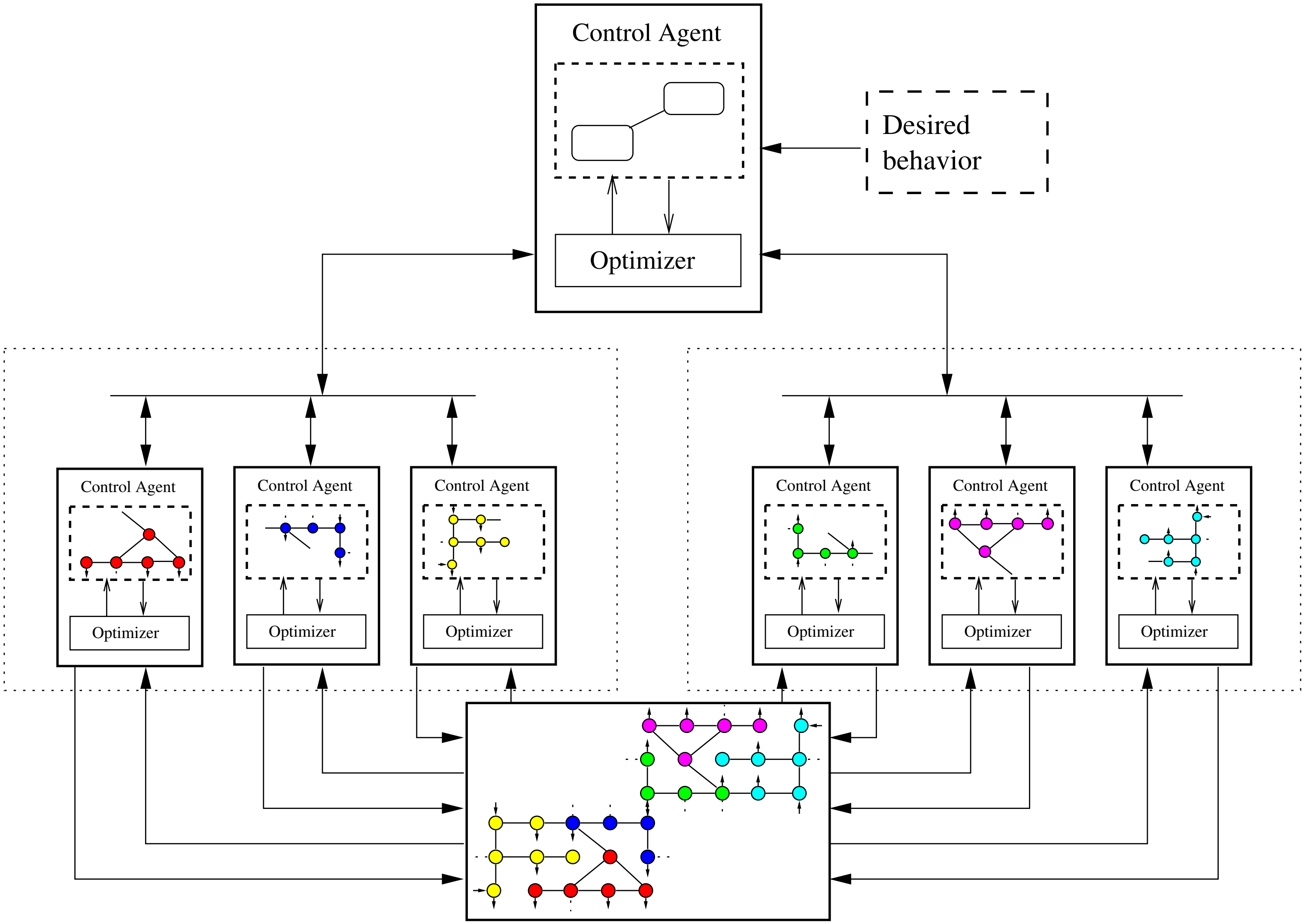
3.2 Multi-agent MPC



3.2 Multi-agent MPC



3.2 Multi-agent MPC



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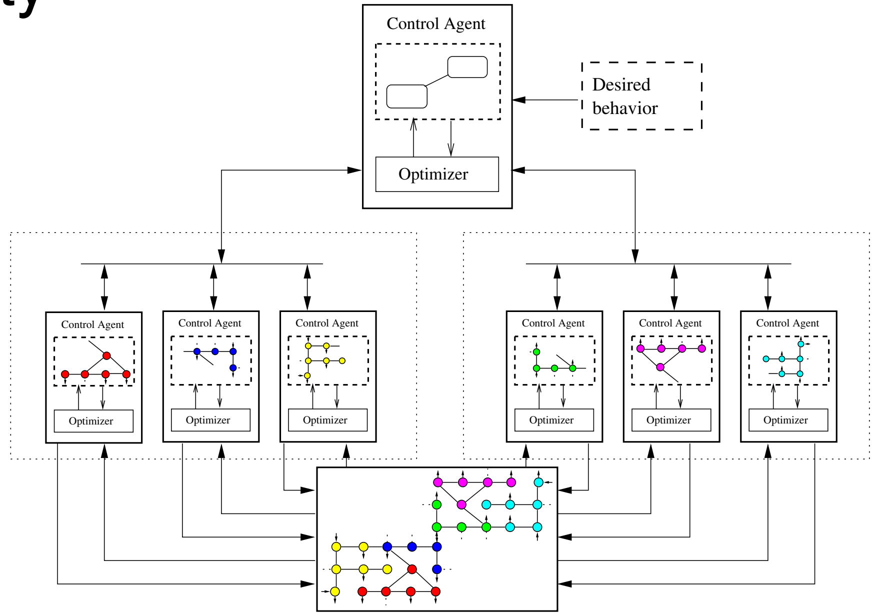
3.2 Multi-agent MPC

General advantages: computational efficiency, reliability, scalability, robustness, maintainability, responsiveness,. . .

Challenge: obtain control goals and coherence, i.e., no chaos and unpredictability

Difficulties:

- no global perspective,
- no global control,
- limited communication.

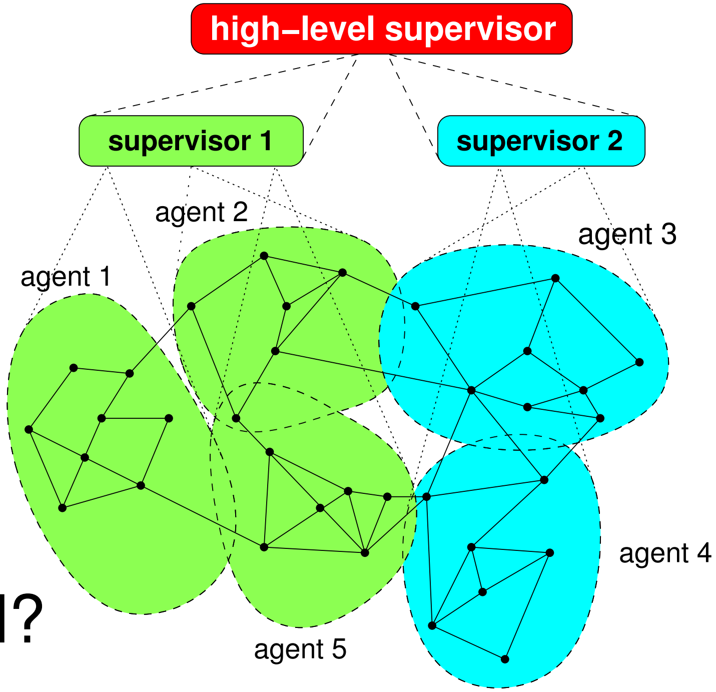


4. Issues to be addressed

How can a problem be decomposed in subproblems?

  How can a network be decomposed in subnetworks?

How should agents communicate info and cooperate their actions?



How well is performance compared to centralized case?

Are multiple levels necessary?

  If so, how should they be organized?

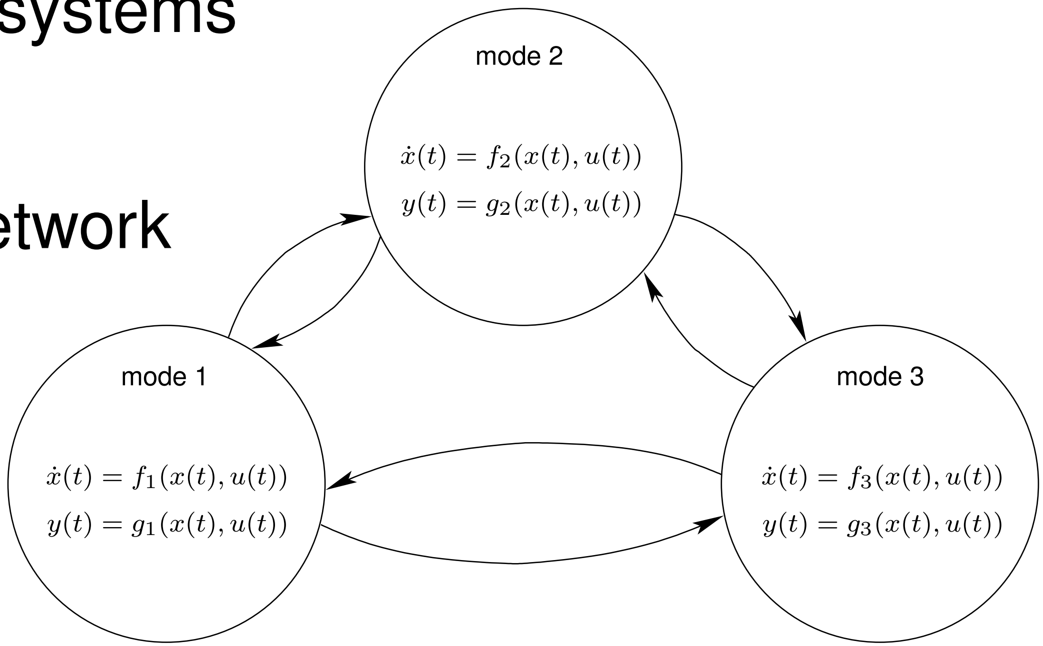
4. Issues to be addressed

Our approach:

- Consider hybrid models of network systems.
  I.e., both continuous and discrete dynamics.

- Apply MPC for hybrid systems to a small network.

- Extend this to large network based on multi-agent MPC ideas.



5. Alternative approach

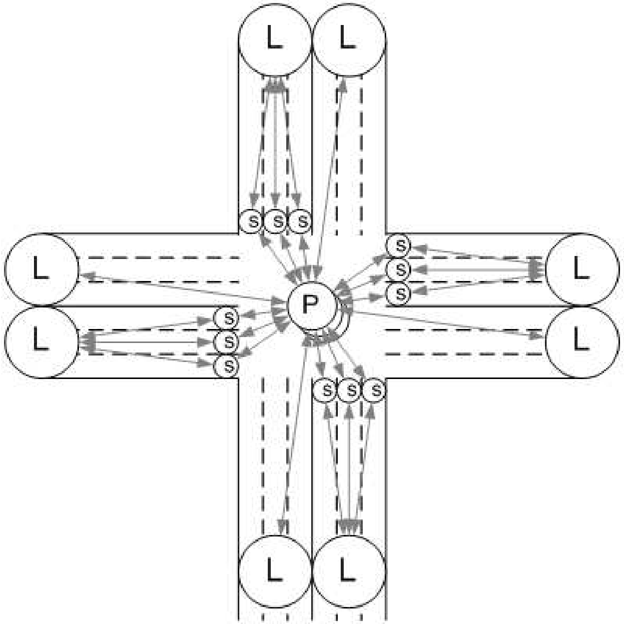
Approach discussed so far: top-down
i.e., from network-wide control to local control.

Alternative approach: bottom-up
i.e., from local control to network-wide control.

5. Multi-agent traffic control

Ronald van Katwijk:

Control of traffic signals at intersections



Objectives:

- Dynamic structure of signal plans
- Dynamic formulation of control problems
- Social formulation of control problems

5. Multi-agent traffic control

Dynamic structure of signal plans

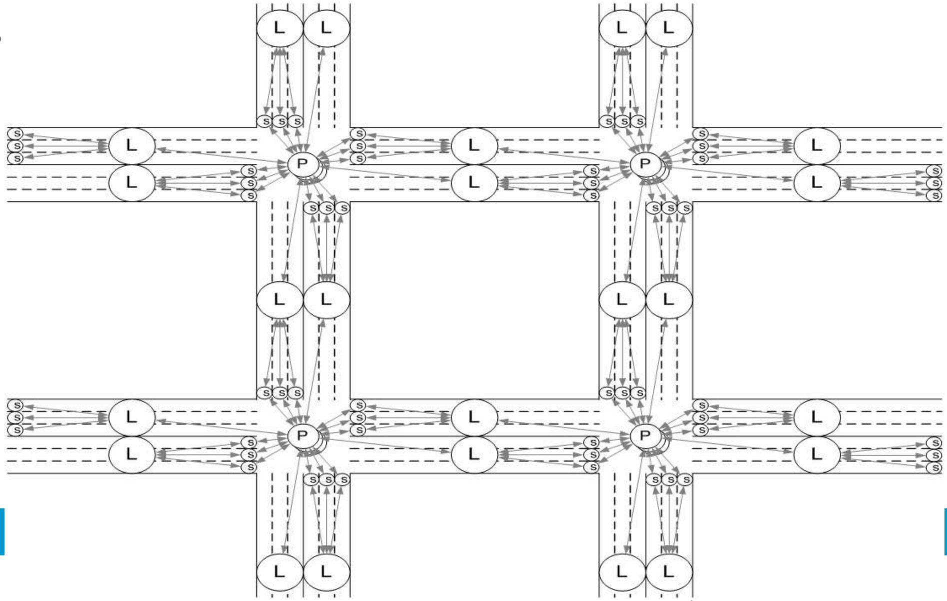
- Negotiated signal plan.

Dynamic formulation of control problem

- Local repair
- Constraint recording

Social formulation of control problem

- Communication between intersections
- Negotiation about actions



6. Questions?