An Optimization Approach for the Network Synthesis of Distributed Embedded Systems

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Outline

- Context & background
- Current limitations
- Methodology
- Experimental results
- Conclusions & Future developments

Context & Background

Distributed Embedded Systems (DESs)

- Distributed applications of Networked Embedded Systems (NESs) interacting together
  - Example: Distributed control of building temperature
- Different types of channels and protocols
- Each NES acts as a **node** of the network
- New design goal
  - *Good behavior of the global application*

Network Synthesis

- Design process starting from a high-level specification of DES
- It finds the actual configuration in terms of
  - mapping of application tasks onto network nodes
  - their spatial displacement
  - the type of channels and protocols among them, and the network topology

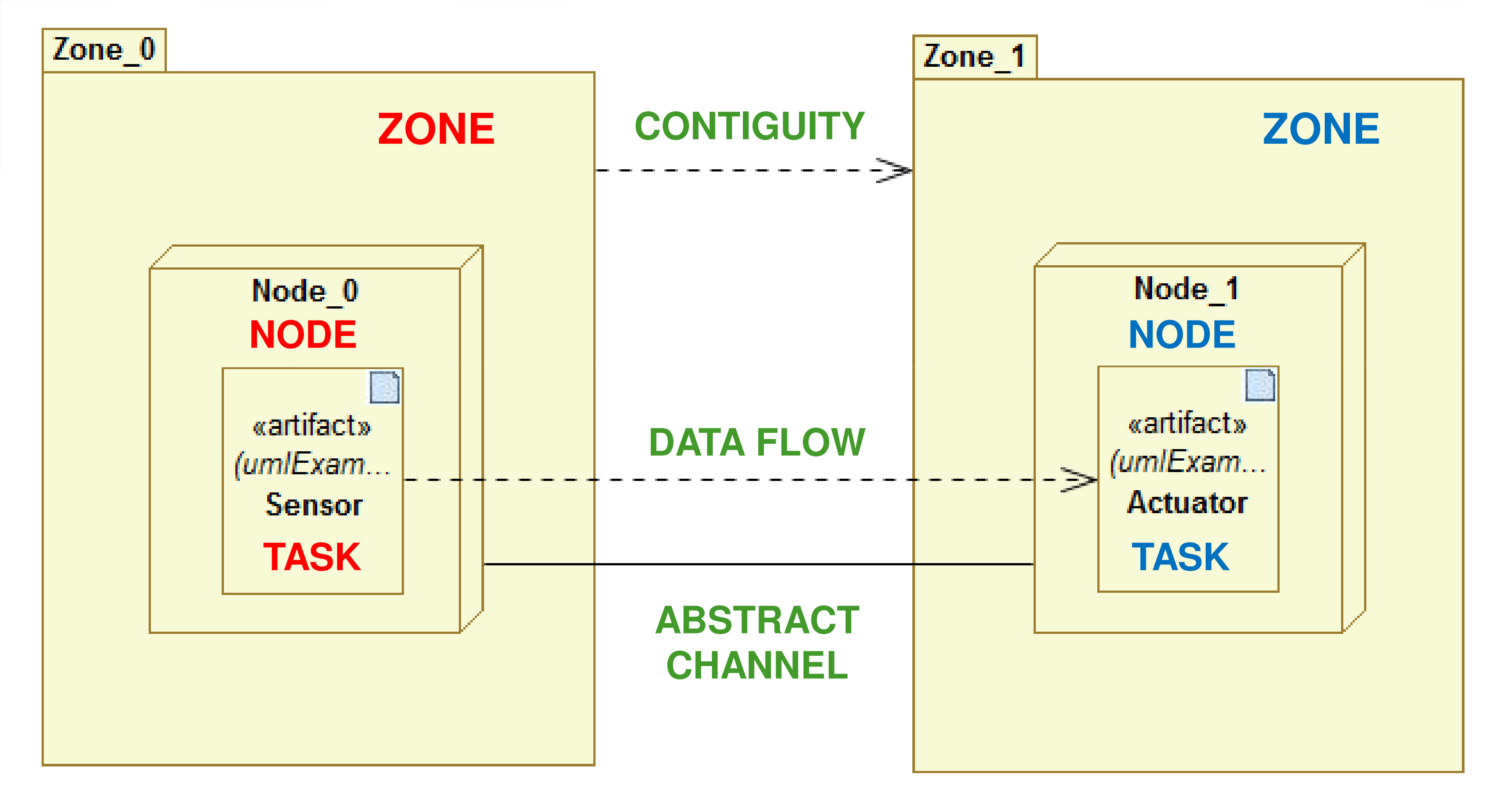
CASSE (1)

- Communication Aware Specification and Synthesis Environment (CASSE), is an extended design flow, which addresses the network synthesis, in terms of nodes, tasks, data flows, abstract channels, zones and contiguities.
  - Tasks
    - A task represents a basic functionality of the whole application; it takes some data as input and provides some output.
    - *Relevant attributes:* *computational requirements, mobility.*
  - Data flows
    - A data flow (DF) represents communication between two tasks; output from the source task is delivered as input for the destination task.
    - *Relevant attributes:* *communication requirements.*
  - Nodes
    - A node can be seen as a container of tasks.
    - *Relevant attributes:* *available computational resources, intrinsic power consumption, power consumption due to tasks, mobility, economic cost.*

CASSE (2)

- Abstract Channels
  - An abstract channel (AC) interconnects two or more nodes.
  - *Relevant attributes:* *available communication resources, economic cost, wireless/wired.*
- Zones
  - A zone is a partition of the space which contains nodes; each zone is characterized by environmental attributes which are application-specific.
- Contiguities
  - Zones are related by the notion of contiguity defined as follows:
    - Two zones are contiguous if nodes belonging to them can communicate each other.
    - Contiguity represents not only the physical distance between zone, but it can be used also to model environmental obstacles like walls.
  - *Relevant attributes:* *resistance.*

UML Deployment Diagram



Purely analytical Optimization

- Process that explores the solutions using techniques unaware of the network context.
- Formulation of the network optimization problem in the form of MILP (Mixed Integer Linear Programming) problem, whose optimization techniques are well known in literature (e.g. Simplex method, Branch-and-bound method).

Current limitations

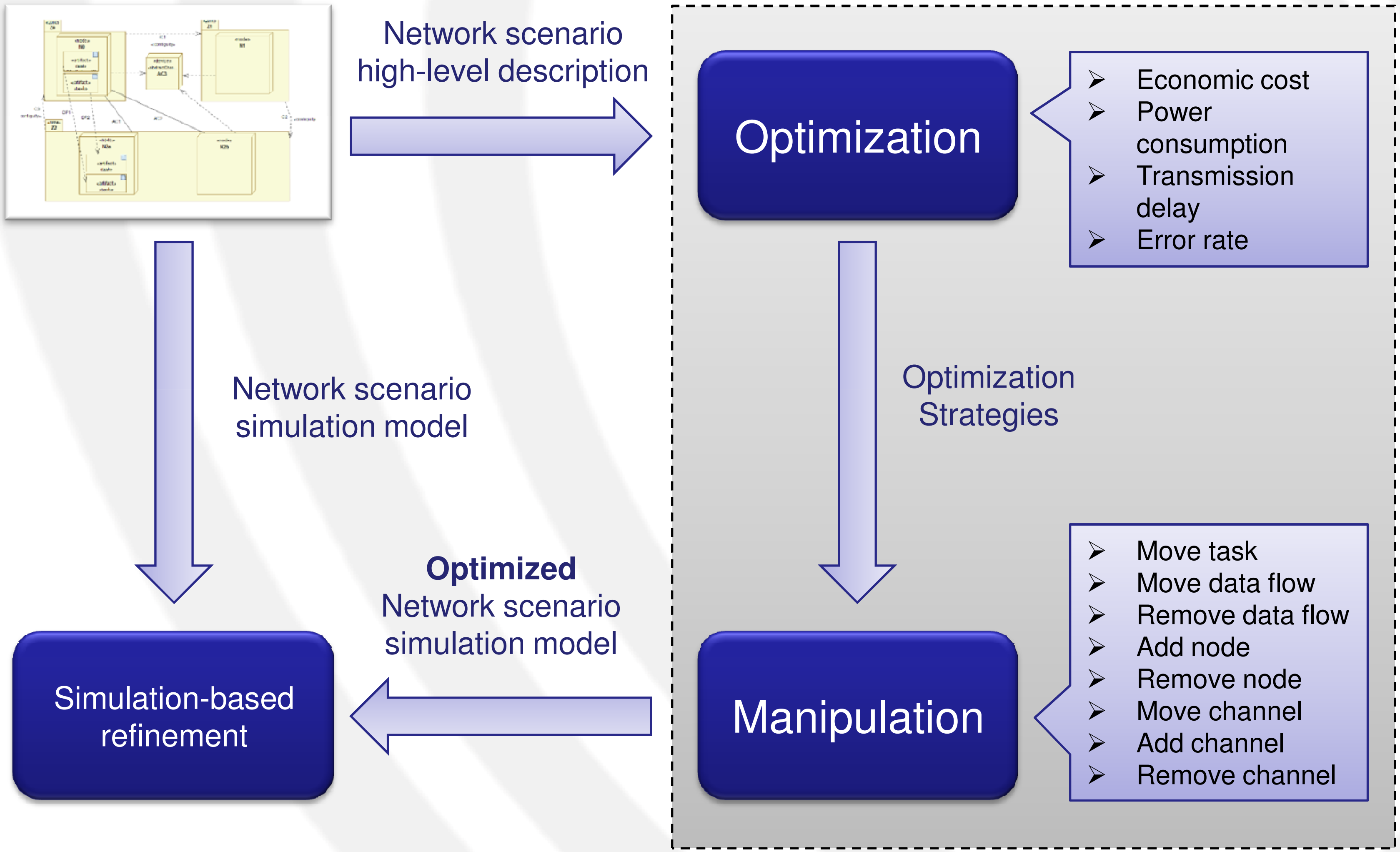
- The increase of the complexity of distributed applications
  - Computer-aided design for the communication infrastructure between nodes of a DES
- Low scalability of pure analytical approaches (e.g., MILP) to the size of a real application
  - Analytical modeling could be combined with **Network Manipulation** driven by an optimization process
- Gap between the ideal model of the network, and the real network
  - Mixed analytical and simulation-based methodology is needed

Methodology

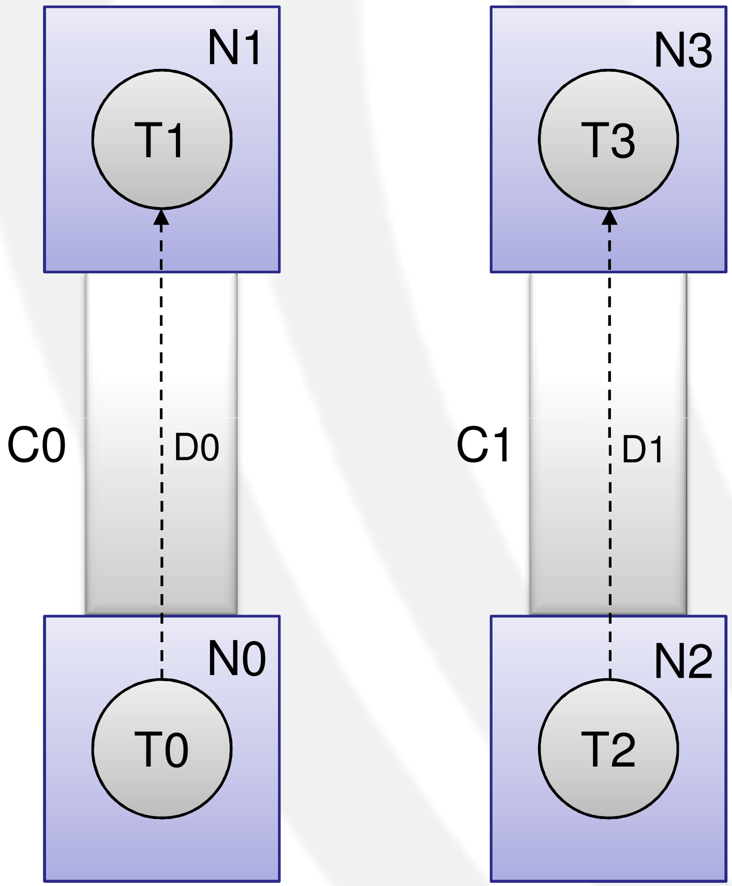
Contributions

- NW-aware approach for the optimal Network Synthesis of DES.
- Methodology to manipulate the DES description from a high level specification to simulation.
- Definition of manipulation rules to alter the network setup according to given optimization goals.
- Use of the network simulation to validate the optimization results and explore other possible solutions.

Flow for optimal Network Synthesis

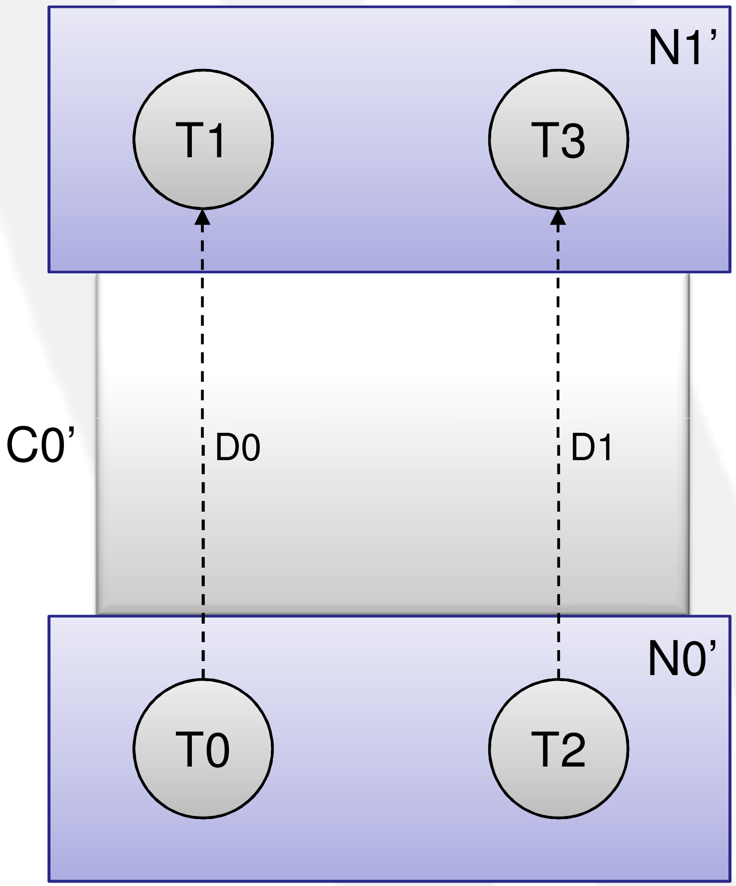


Optimization problem (1)



- nodes N0, N1, N2, N3
- tasks T0, T1, T2, T3
- channels C0, C1
- data flows D0, D1

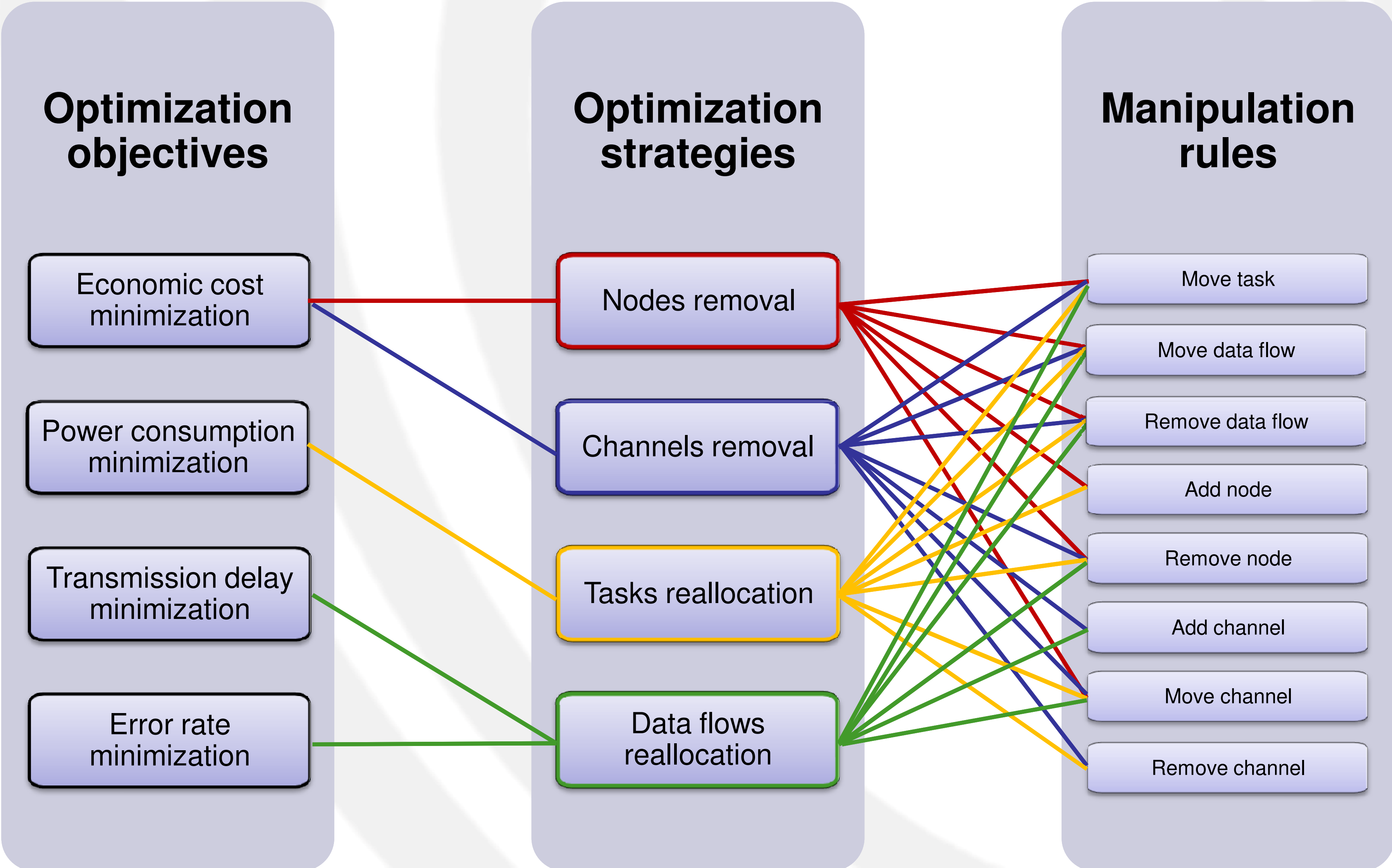
Optimization problem (2)



PROBLEMS:

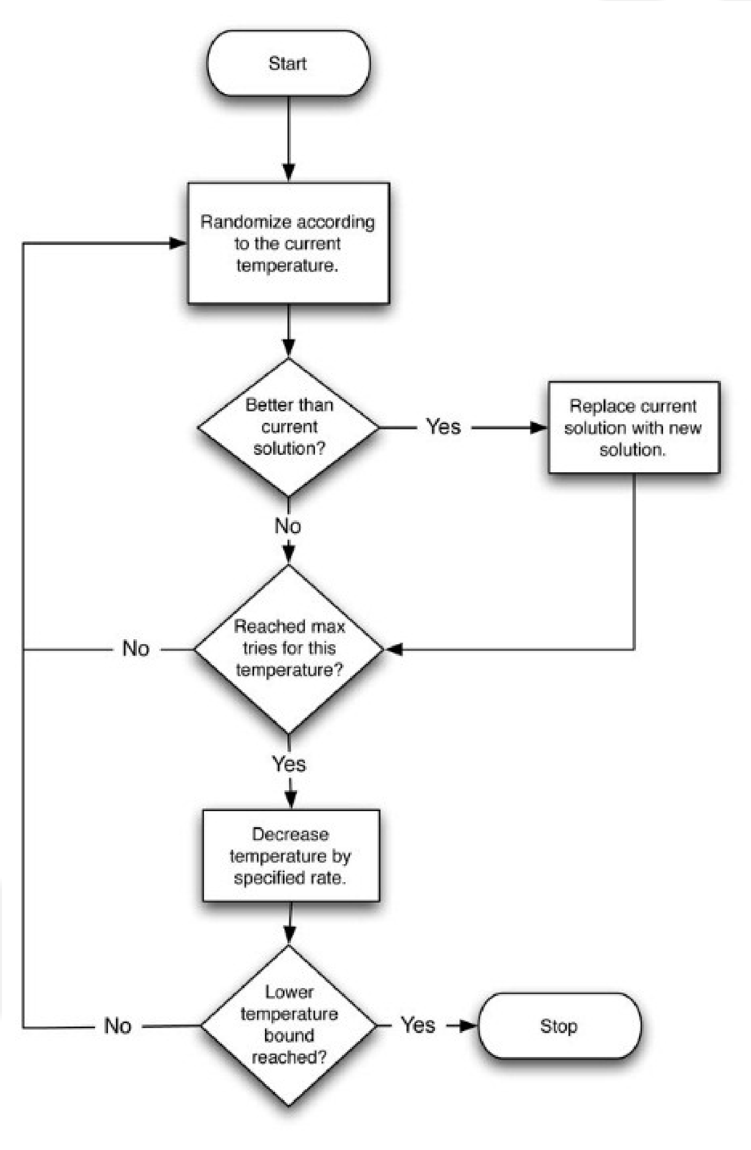
- How to split this transformations into elementary steps?
- How to link elementary transformations to optimization goals?

NW-Aware Optimization

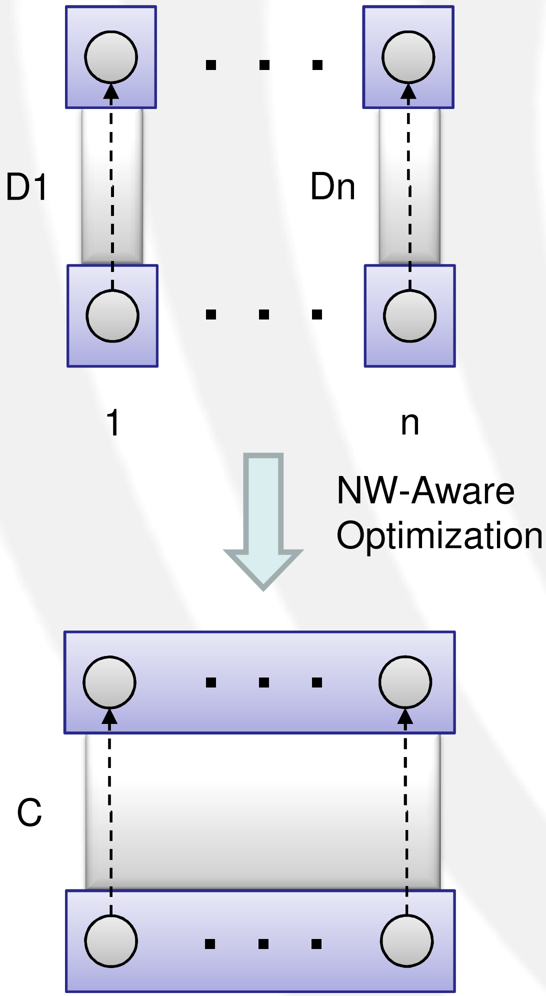


Simulated Annealing

- Generic probabilistic metaheuristic for the global optimization problem of locating a good approximation to the global optimum of a given function.
- Aims to find a global optimum when many local optima are present.
- Often used when the search space is large and also discrete.



Ideal model vs. Actual behavior (1)



For each *i-th* data flow we define its throughput as:

$$Th(D_i)$$

Ideally, the used capacity of channel C should be:

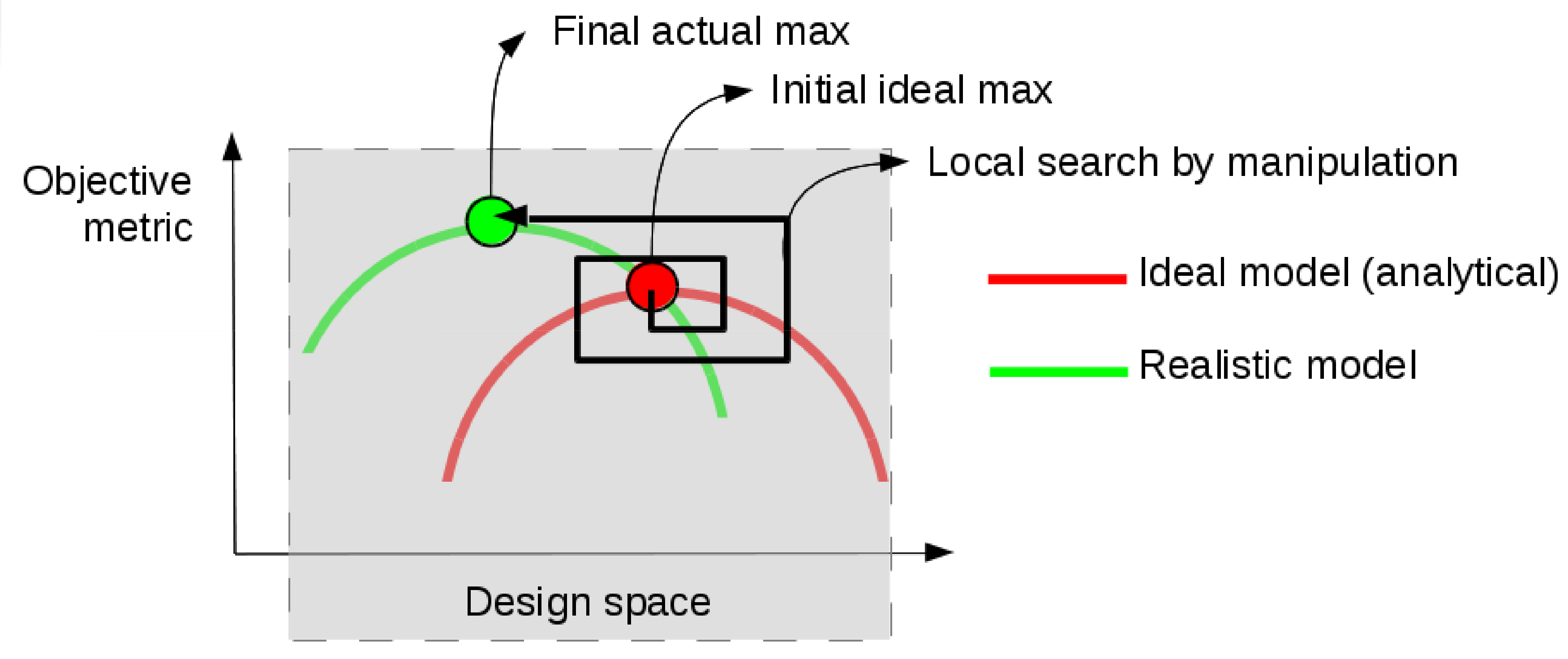
$$\sum_{i=1}^{n} Th(D_i)$$

NOT ALWAYS TRUE!
e.g., overhead of the wireless protocols

Non-idealities

- In the Network-aware Optimization process we make some ideality assumptions which often don’t correspond to reality.
- For this reason we make a list of non-ideality factors that we are not able to take fully into account in the Network-aware optimization approach:
  - from the point of view of the Network
  - from the point of view of the Nodes
  - from the point of view of the Power consumption
  - from the point of view of the HW Architecture

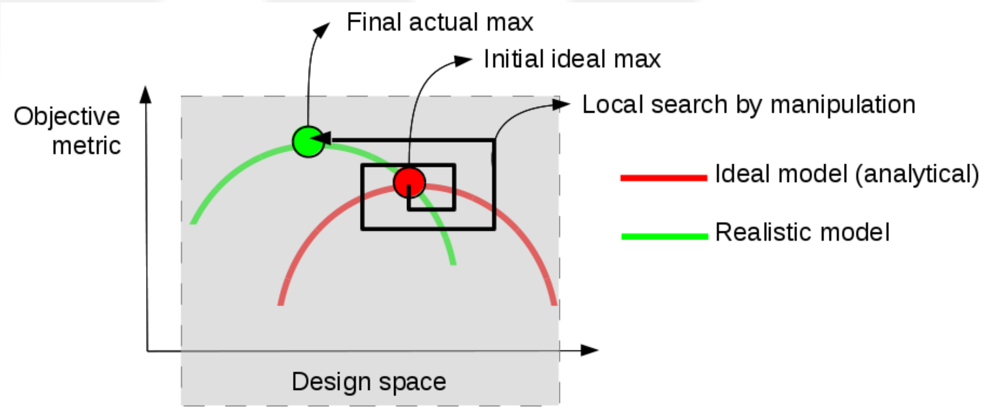
Ideal model vs. Actual behavior (2)



Simulation

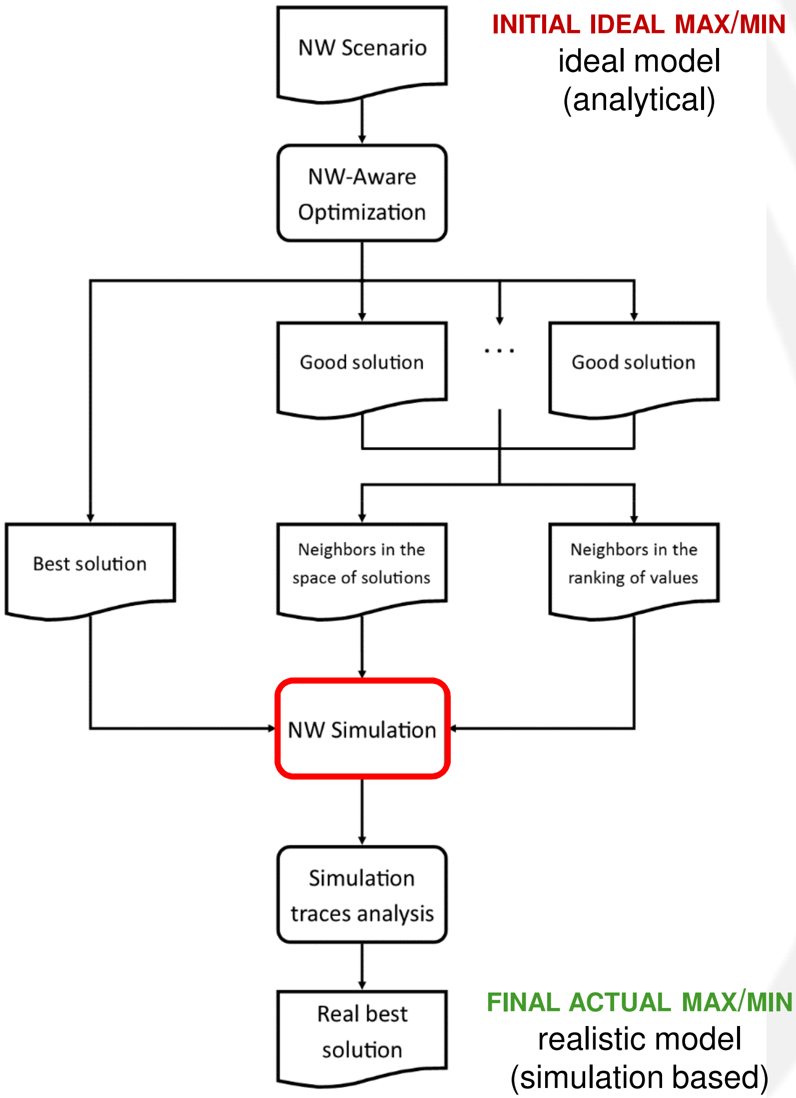
- To take into account the non-ideality factors in the optimization process, we are going to use the simulation applied to:
  - Points close to the optimal obtained with the manipulations
    - Neighbors in the solution space
  - Points close to the optimal obtained with the manipulations
    - Neighbors in the ranking of the best solutions found
- Network Simulation lets us to refine the choice of candidate solutions for those objectives that operate on parameters verifiable through simulation (e.g. delay, error rate).

Simulation-based refinement

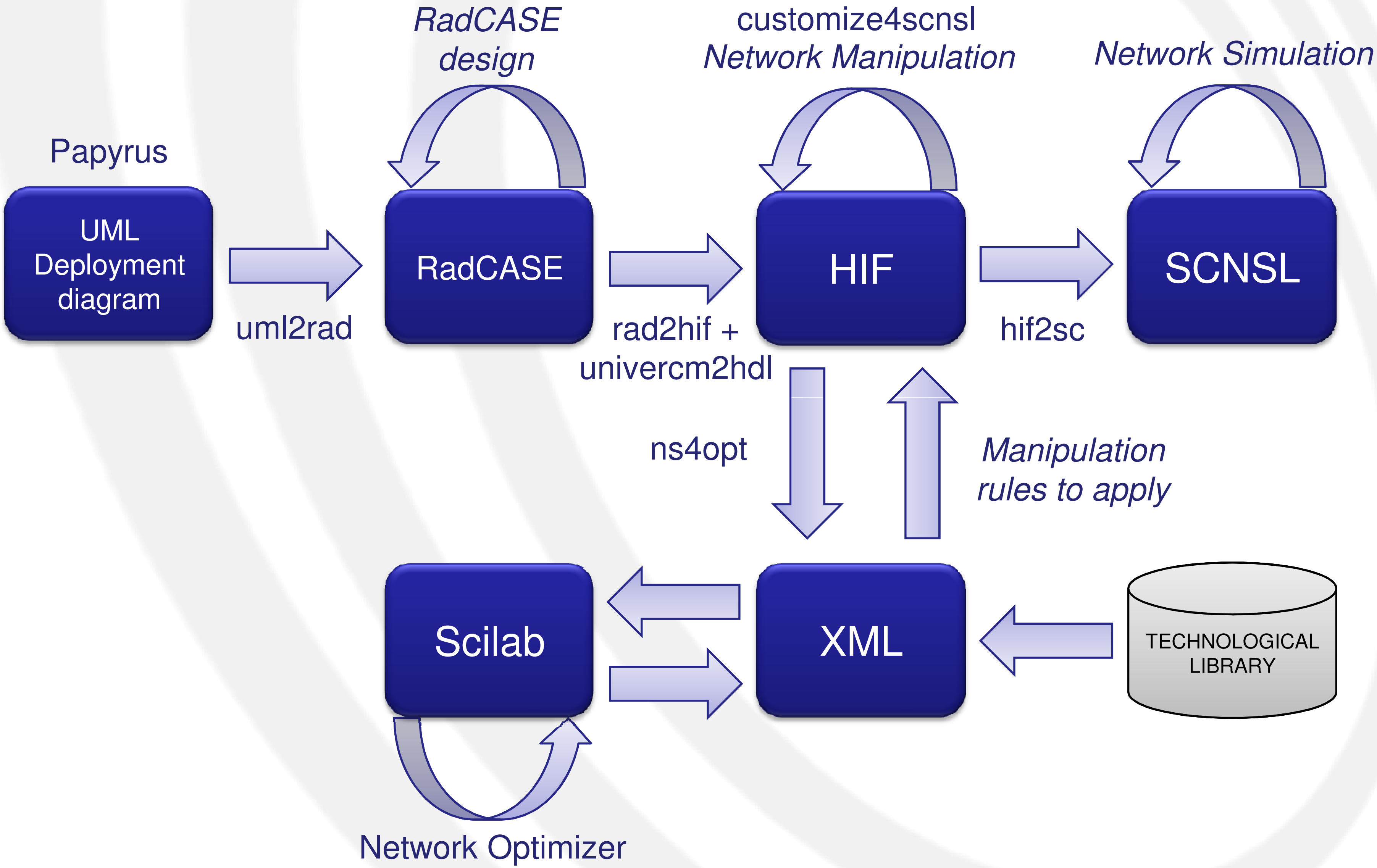


Considering neighbors of the optimum ideal max in

1. the space of solutions
2. the ranking (with respect to the optimization metric)

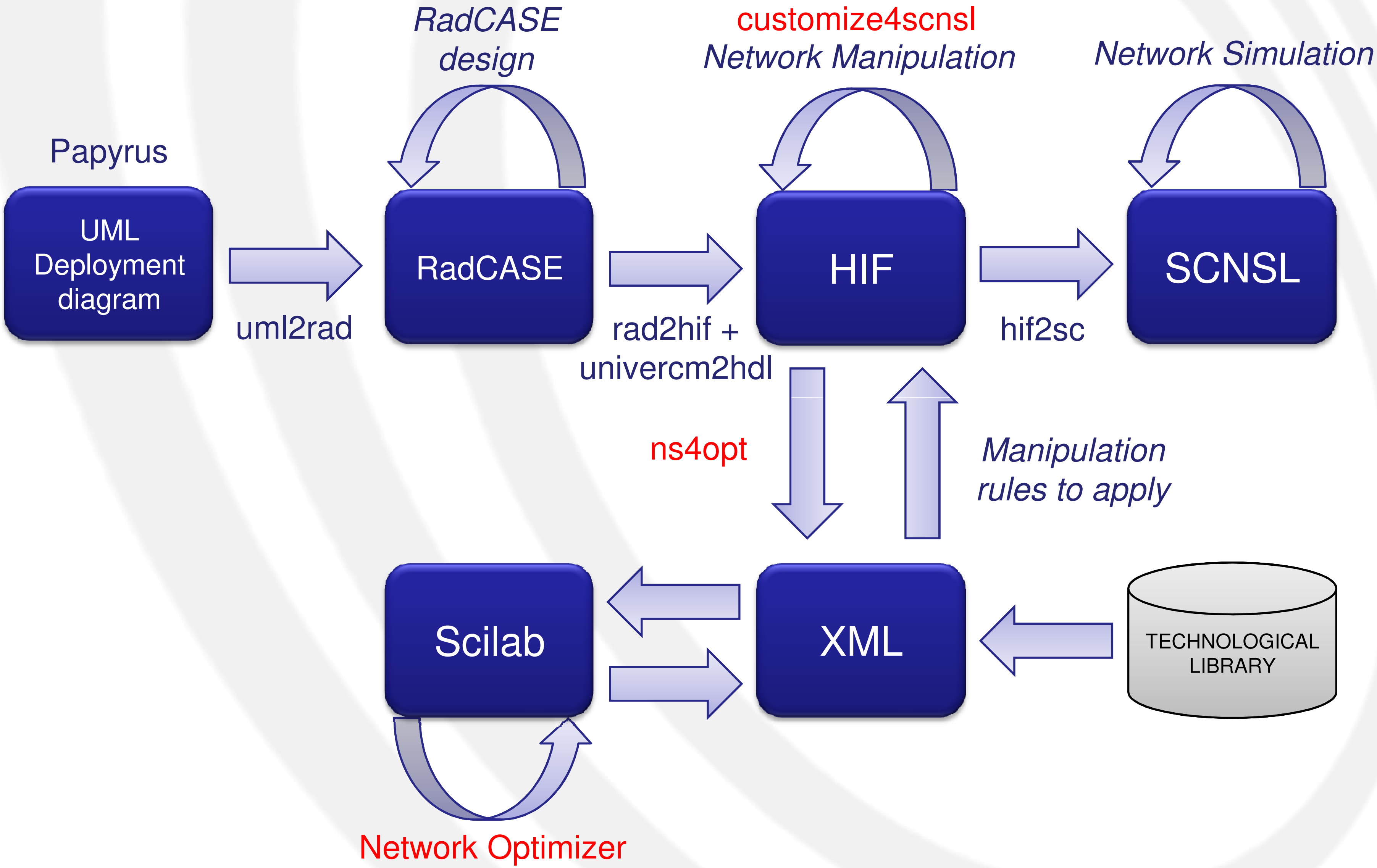


Toolchain



RadCASE design
customize4scnsl Network Manipulation
Network Simulation
Papyrus
UML Deployment diagram
uml2rad
RadCASE
rad2hif + univercm2hdl
HIF
hif2sc
SCNSL
ns4opt
Manipulation rules to apply
Scilab
XML
TECHNOLOGICAL LIBRARY
Network Optimizer

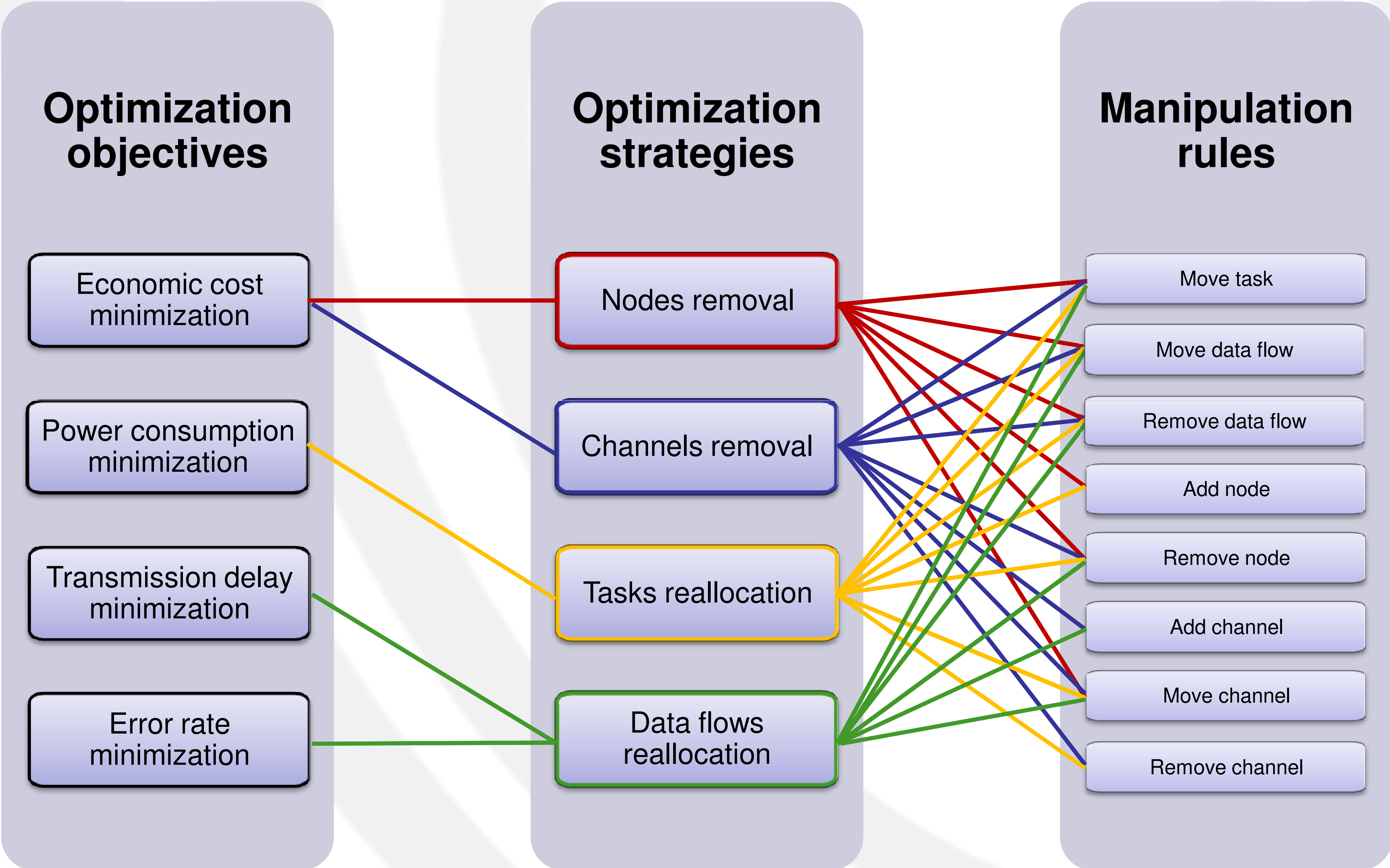
Toolchain



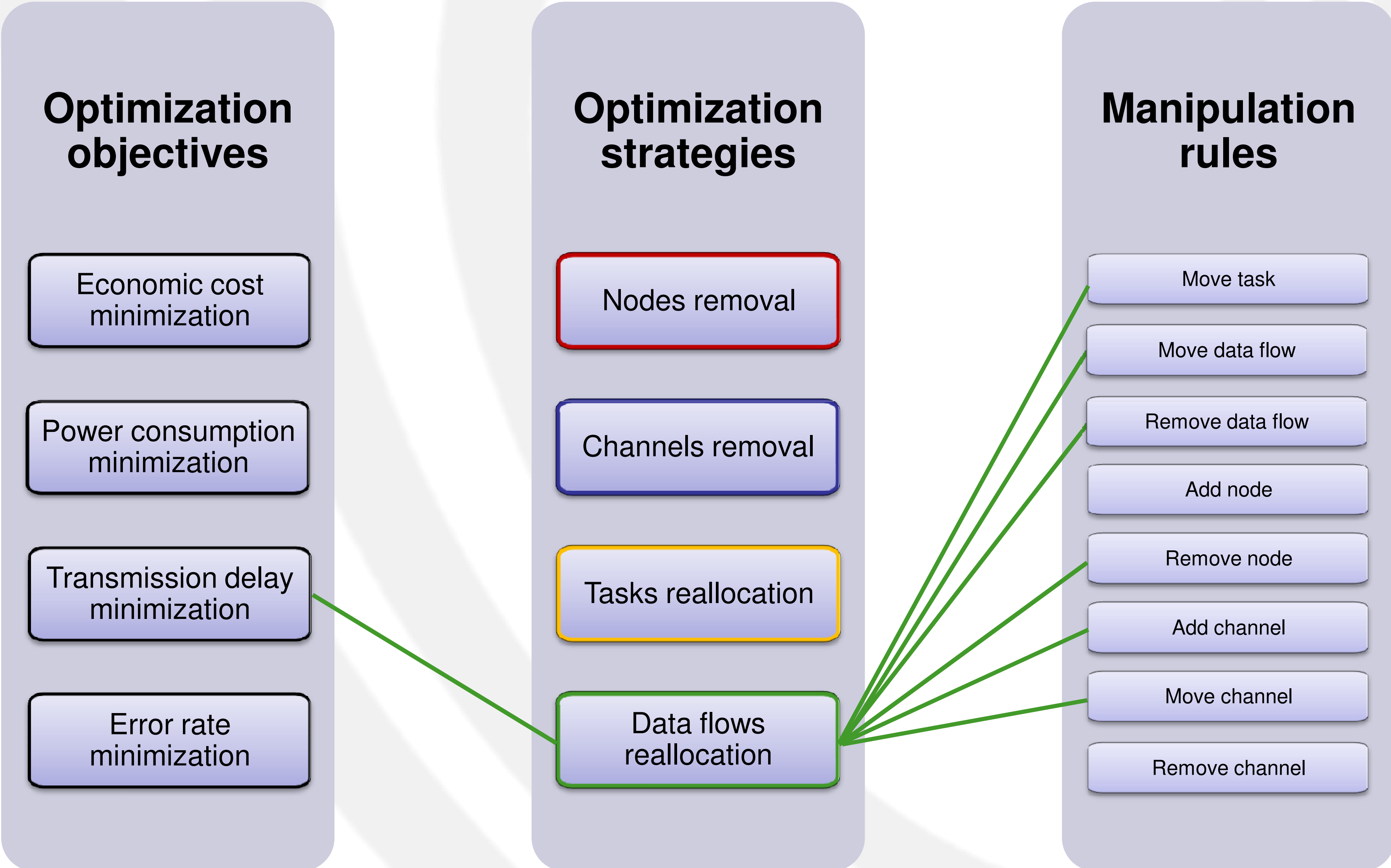
RadCASE
design
customize4scnsl
Network Manipulation
Network Simulation
Papyrus
UML
Deployment
diagram
uml2rad
RadCASE
rad2hif +
univercm2hdl
HIF
hif2sc
SCNSL
ns4opt
Manipulation
rules to apply
Scilab
XML
TECHNOLOGICAL
LIBRARY
Network Optimizer

Experimental results

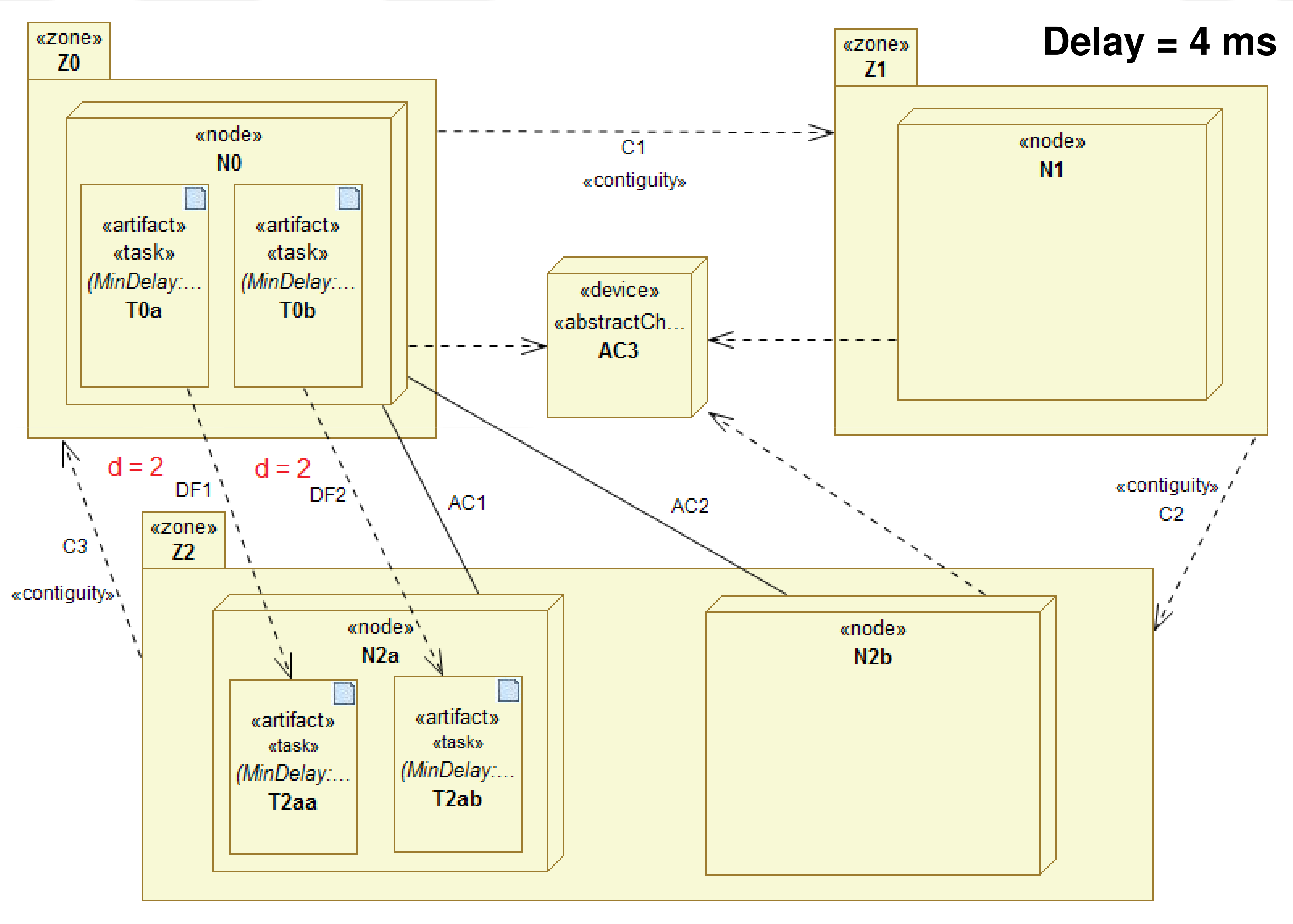
NW-Aware Optimization



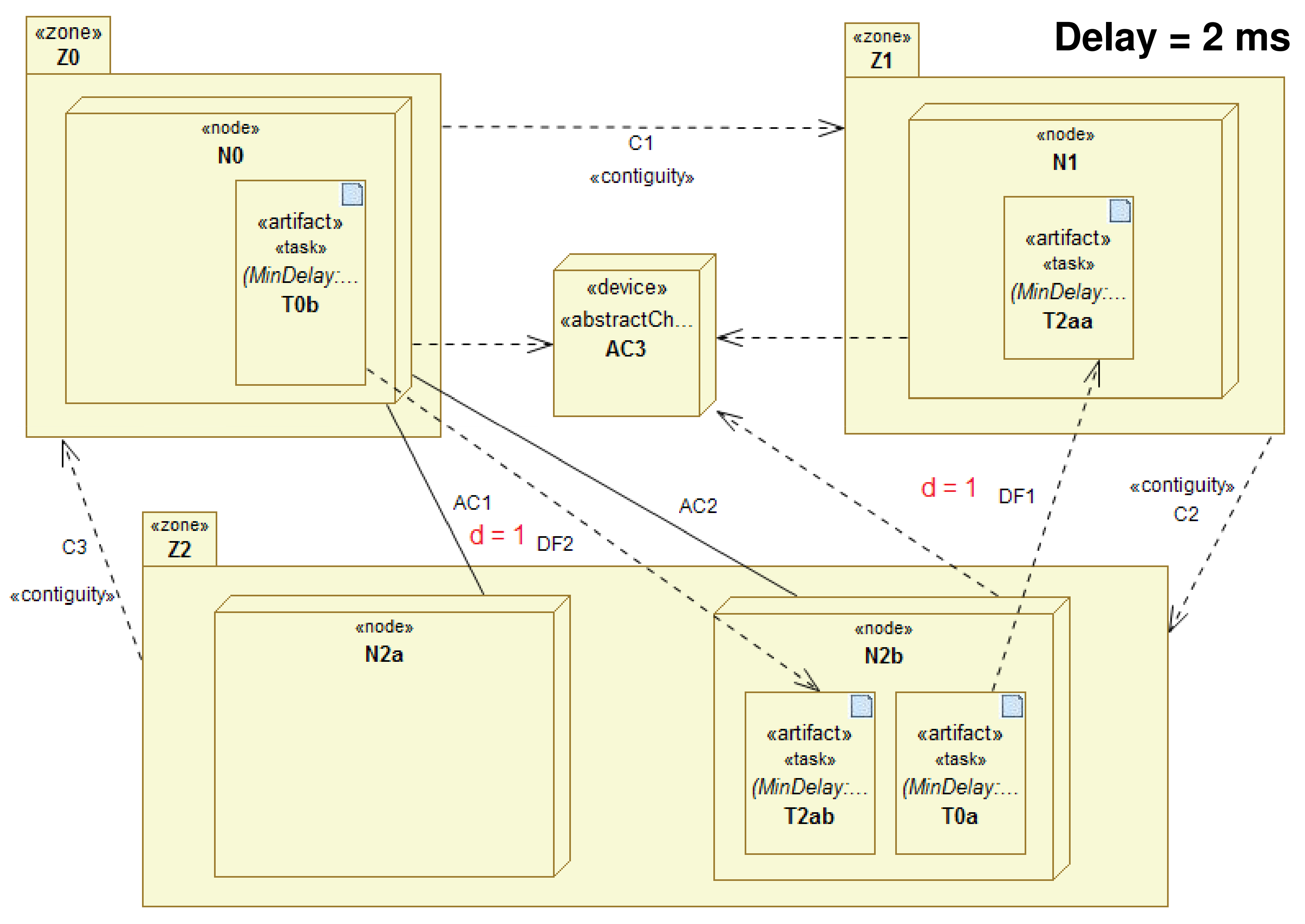
Transmission delay minimization



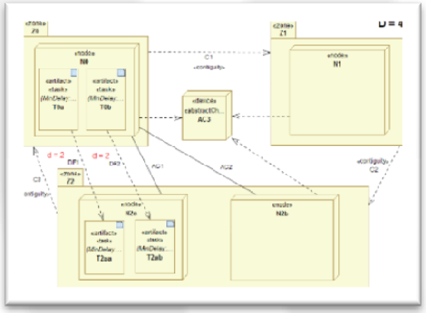
Experimental results (before)



Experimental results (after)



Validation through simulation



Network scenario
high-level description

Network scenario
simulation model

```
800 us T0a data sent: A bytes: 1
800 us T0b data sent: B bytes: 1
2800 us T2aa data received: A bytes: 1
2800 us T2ab data received: B bytes: 1
```

```
800 us T0a data sent: A bytes: 1
800 us T0b data sent: B bytes: 1
1800 us T2aa data received: A bytes: 1
1800 us T2ab data received: B bytes: 1
```

Optimized
Network scenario
simulation model

Optimization

- Transmission delay

Optimization
Strategies

Manipulation

- Move task
- Move data flow
- Remove data flow
- Remove node
- Move channel
- Add channel

Conclusions &
Future developments

Conclusions

- New methodology for the optimal network synthesis of Distributed Embedded Systems.
- Validation of the optimization process results through network simulation.
- Set of tools in support of the optimization process from the UML description to the SCNSL simulation model.

Future developments

- Extension of the set of optimization objectives
  - Introduction of new optimization strategies
  - Introduction of new manipulation rules
- Further integration of the network simulation in the optimization process.
- Adaptation of the methodology for a Multi-objective optimization.