Design flow for Networked Embedded Systems

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Outline

- Introduction and motivation
- Background
- Proposed methodology
- Modeling requirements
- System view simulation
- Network synthesis
- Network view simulation
- Case study
- Conclusion

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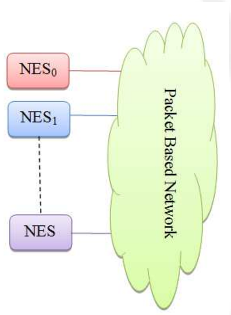
Introduction

- **Networked Embedded Systems (NES)** are an important class of devices
  - Network functionalities are at the core of design objectives
  - Network requirements come together with traditional requirements
- **Distributed Embedded Systems** are group of NES which are connected together using network interfaces, standardized protocols and channels
  - Example: Temperature control of a building



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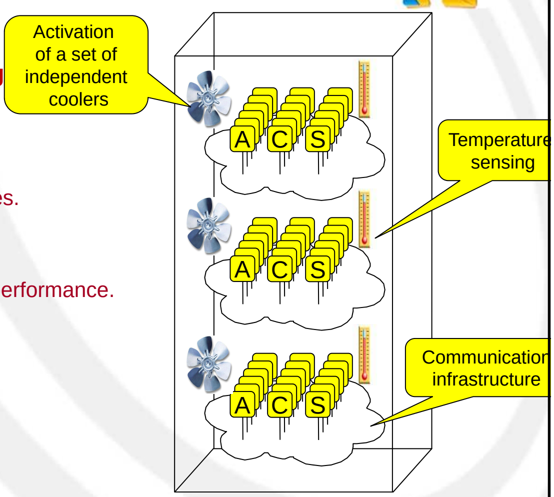
Introduction

Temperature control of a building

- Scenario:
  - Hundreds of concurrent tasks.
  - Heterogeneous tasks.
  - Devices with different capabilities.
  - Wireless and wired channels.
  - Many communication protocols.
  - Nodes position affects system performance.
- Questions:
  - How many nodes?
  - How to assign tasks to nodes?
  - Which network protocols?
  - Which intermediate systems?



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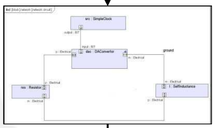
Introduction

Traditional design flow for embedded systems:

Application requirements: functional & non-functional

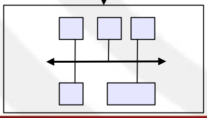


Model-driven design

Platform description:
IP blocks (CPU, memory, ASIC)

Design-space Exploration (DSE)

HW/SW partitioning



Final result

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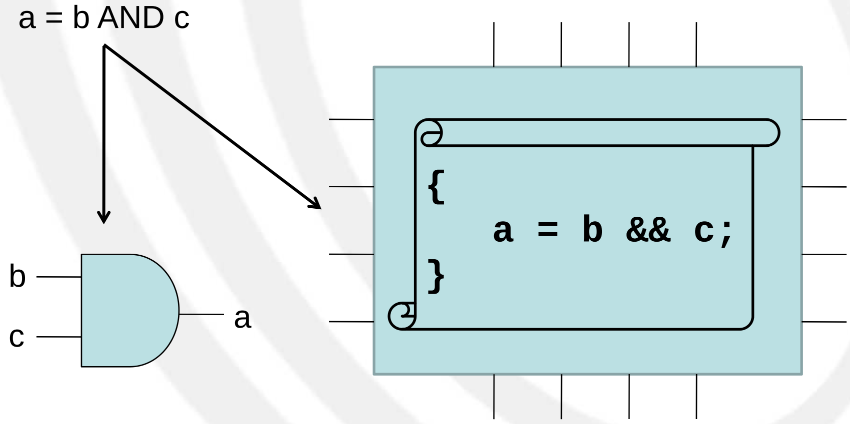
Introduction

HW/SW partitioning:

a = b AND c



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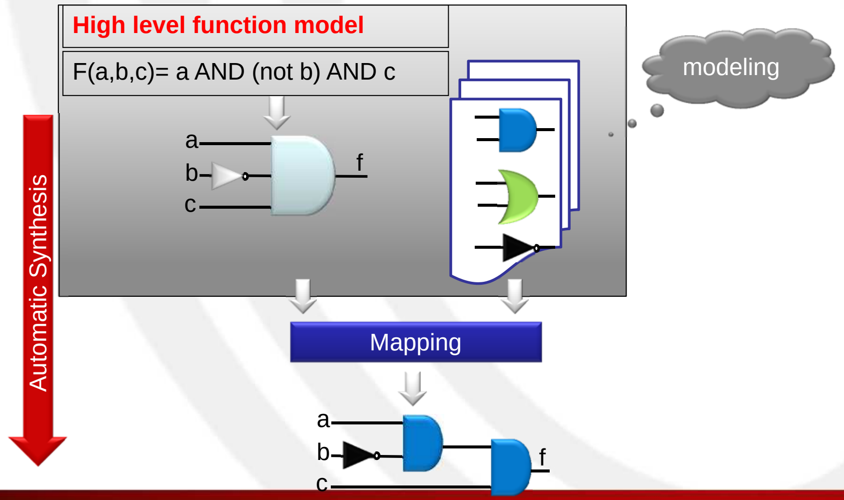
Introduction

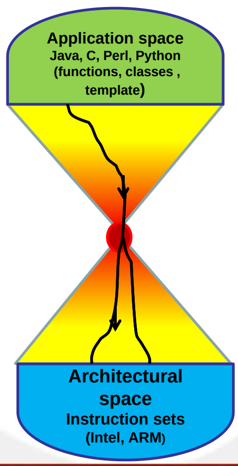
Hardware design:



Introduction

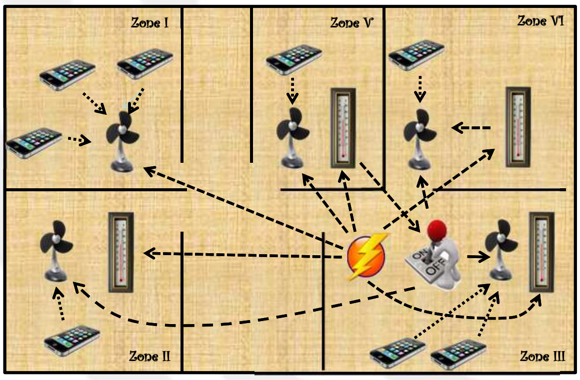
Software development

- Functionality is described with different languages and an automatic process is used to generate assembly code for different target CPU's
- **Modeling** of the functionality: High level languages
- **Automatic synthesis**: Compilers



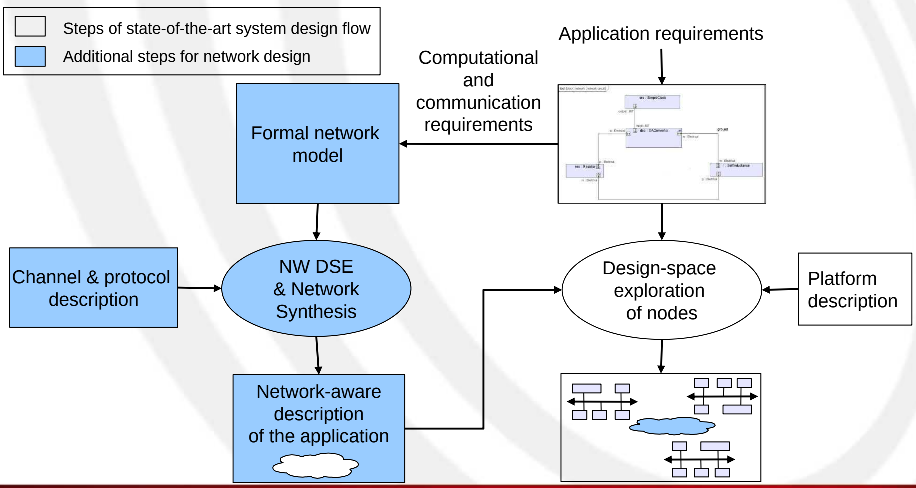
Introduction

- **Distributed embedded application** as a single system to be designed



Introduction

New design flow for NES



Introduction

- Start from an abstract Model-Based System Specification
- Modeling and Analysis of Real-Time and Embedded Systems (MARTE) profile for the unified modeling language (UML)
- Refinement steps and simulations
- Standard representation of requirement and solutions

UML MARTE

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Background

- Design of the network infrastructure starting from a library of nodes and channels (Network synthesis)
  - Communication Aware Specification and Synthesis Environment (CASSE), [FDL 2010]
  - COmmunication Synthesis Infrastructure framework (COSI), [IEEE TASE '12]
- **Open issue :** Both approaches do not rely on a standard representation of requirements (from the initial user specification) and solutions

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Key idea

Design methodology for networked embedded systems which combines UML/MARTE, network synthesis, and simulation

UML/MARTE not only at the starting point but also at the center of design flow as repository of refined version of the system up to the final solution

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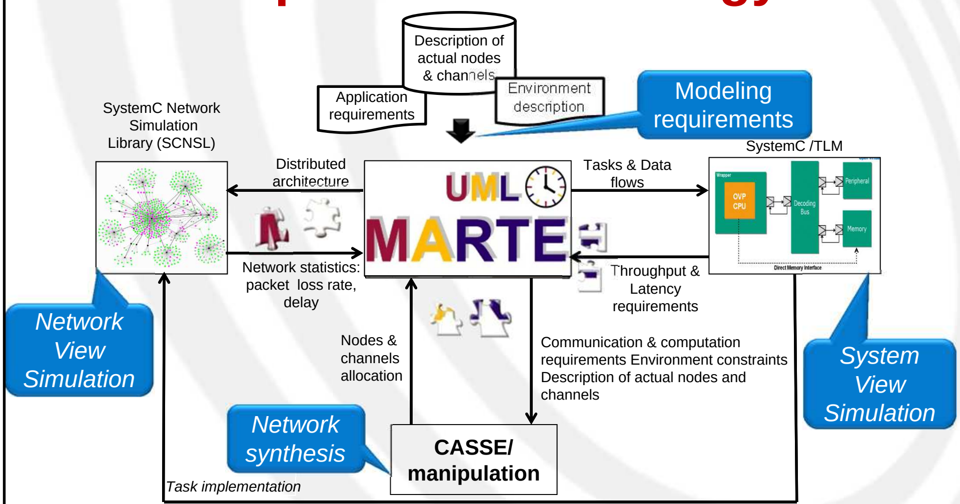
Proposed methodology



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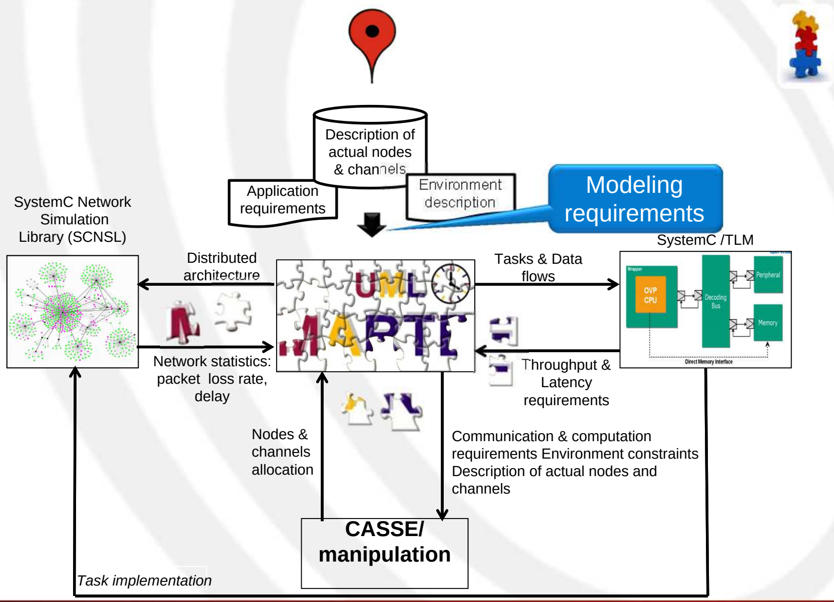

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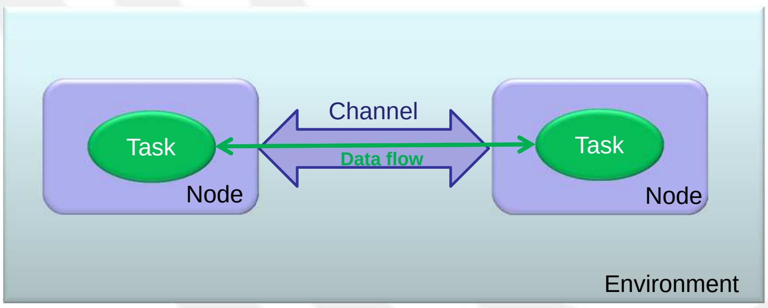
Modeling requirements

- The main aspects to be represented in UML/MARTE are:
  - Tasks, data flows, nodes, channels and the external environment



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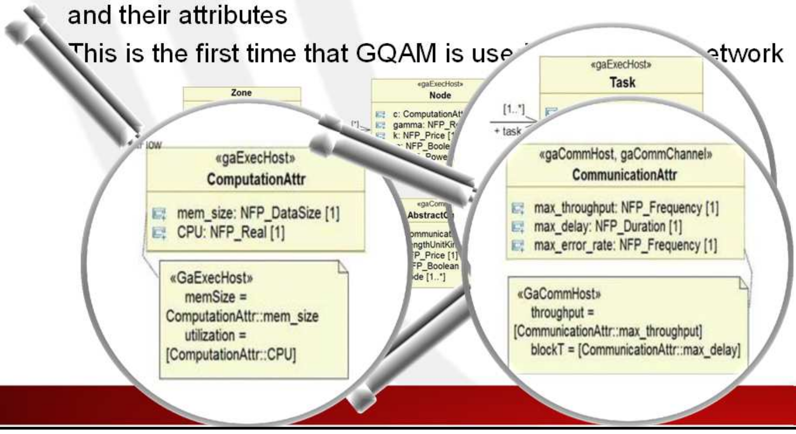
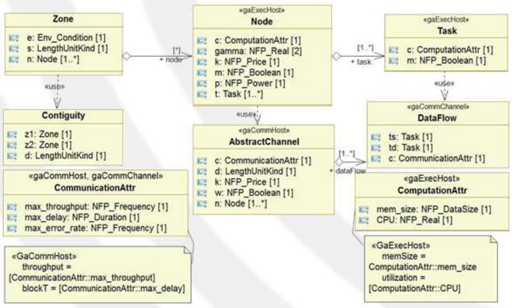
Modeling requirements

- Generic Quantitative Analysis Modeling (GQAM) sub-profile of MARTE profile are used to specify the semantics of some classes and their attributes
- This is the first time that GQAM is use... etwork



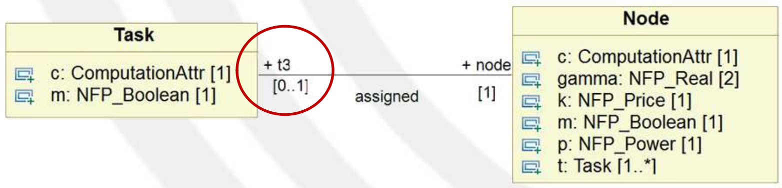
Modeling requirements

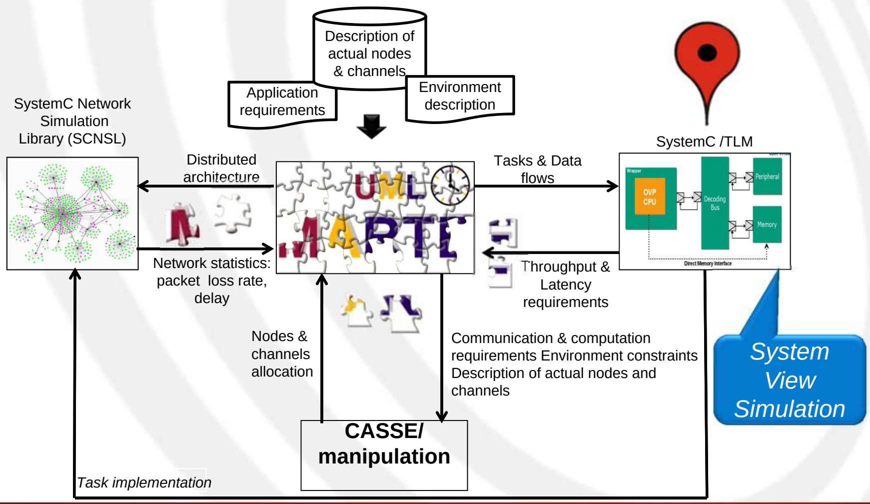
- Generic Quantitative Analysis Modeling (GQAM) sub-profile of MARTE profile are used to specify the semantics of some classes and their attributes
- This is the first time that GQAM is used to model the network



Modeling requirements

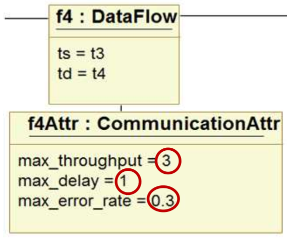
- Modeling of constraint:
  - Application constraints are specified by using cardinality on the relationships between classes
- Example of constraint: *"maximum one instance of t3 can be assigned to a single node"*





System view simulation

- UML/MARTE class diagram is extracted and used to generate SystemC/TLM model
  - Transformations are straight forward also (Villar,2009 and Vanderperren,2008)
- Execution of the SystemC model
  - Validate of functional behavior of the application
  - Fine-tune implementation details such as the content of exchanged messages and their sending rates
- Back annotation of throughput, latency and max error rate inside UML/MARTE model



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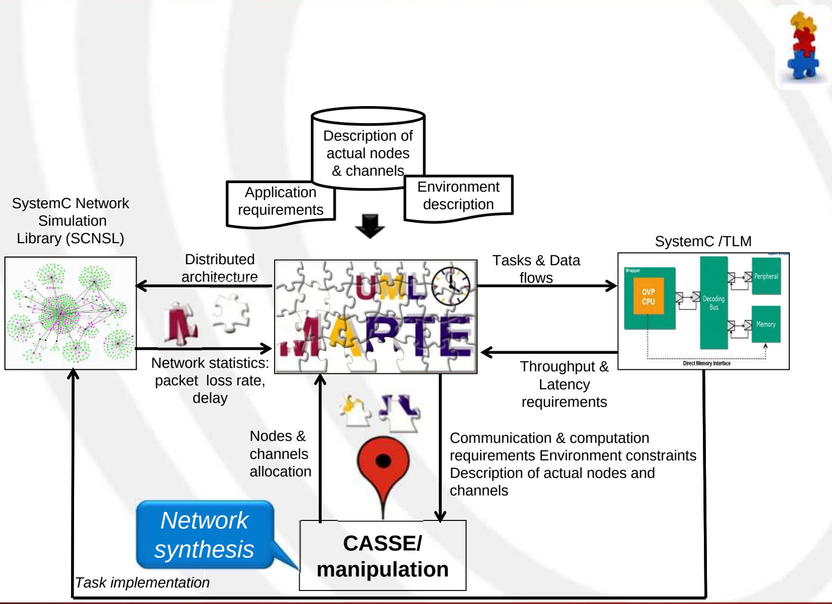

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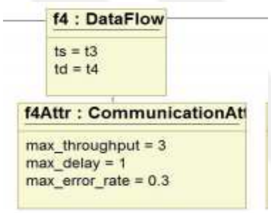
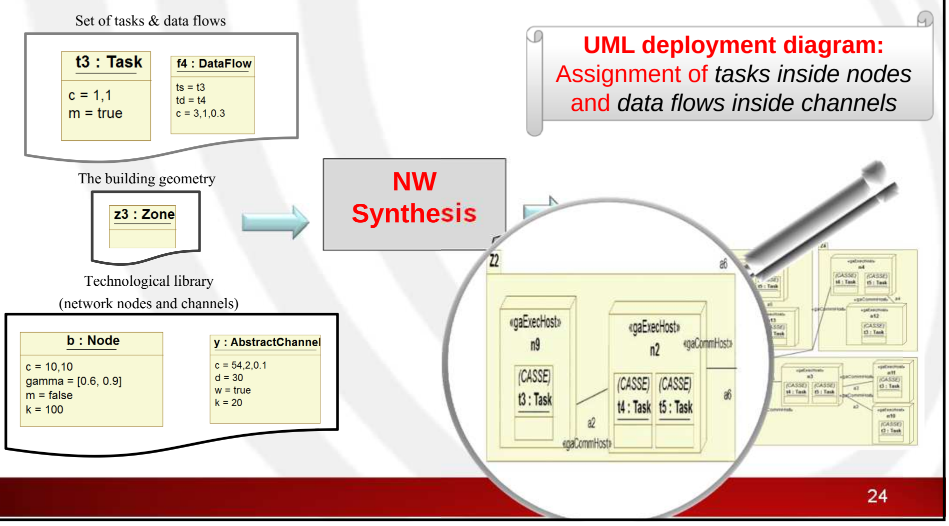
Network synthesis

- All the information about user constraints, communication requirements and actual channels and nodes are extracted from the UML/MARTE model and translated into Network synthesis mathematical representation
- CASSE provides a mathematical notation to specify the network dimension of a distributed embedded system, preparing the way for network synthesis



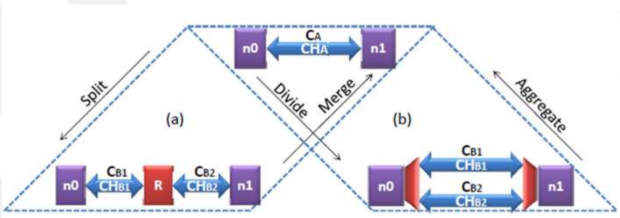
Dataflow(f4) = [t3, t4, [3, 1, 0.3]].

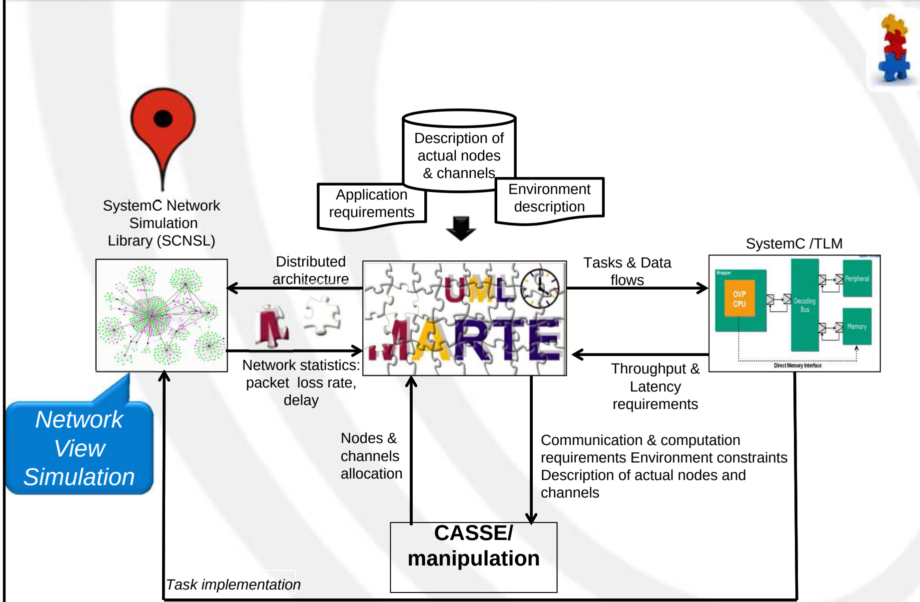
Network synthesis cont'd



Manipulation

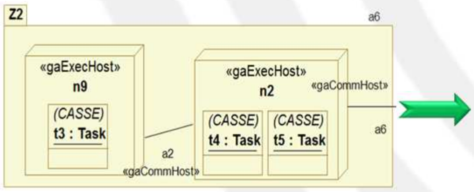
- This step aims at obtaining several NW alternatives which are equivalent from the network perspective
- Mathematical-based rules
  - Divide
  - Split
  - Merge
  - Aggregate



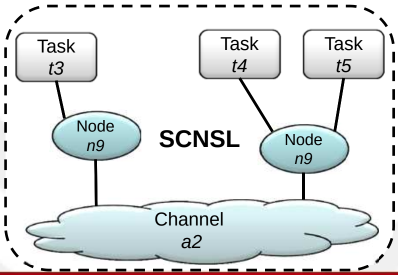


Network view simulation

- SCNSL is an extension of SystemC to allow modeling packet-based networks
  - It allows the easy and complete modeling of distributed applications of networked embedded systems such as wireless sensor networks, routers, and distributed plant controllers



UML deployment diagram



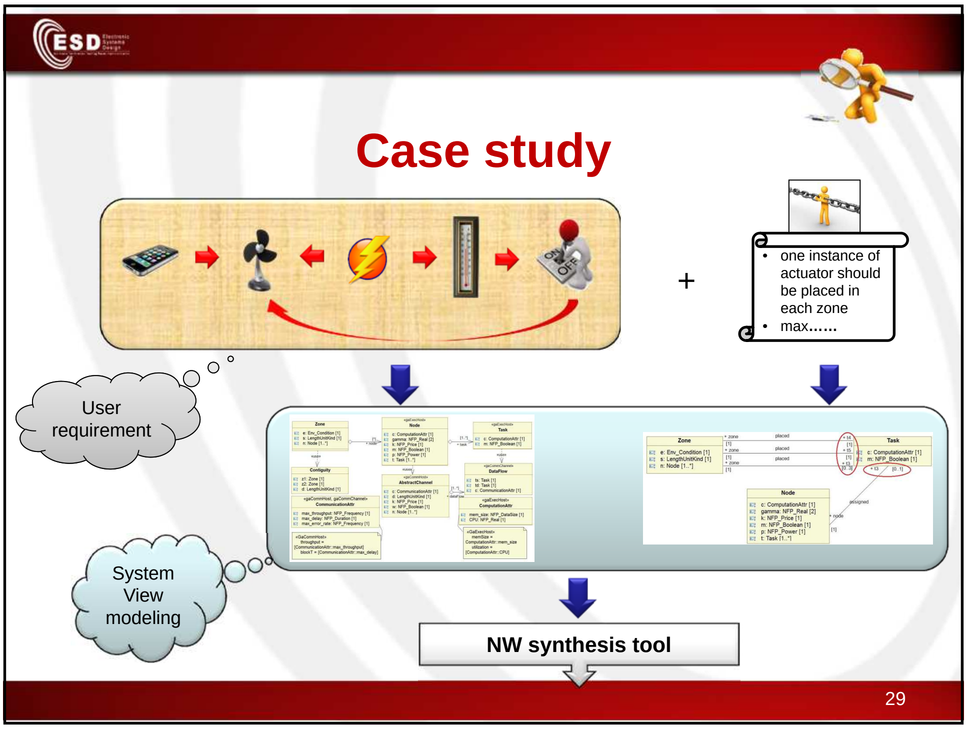
Network view simulation

- Correspondence between UML/MARTE and SCNSL elements

UML/MARTE	SCNSL
Node (n1)	n1 = scnsl->createNode();

Channel (ch)
bound to node (n1)
	CoreChannelSetup t ccs;
	ch = scnsl->createChannel(ccs);
	BindSetup base t bsb1;
	scnsl->bind(n1,ch,bsb1);

Data flow between task (t1)
and task (t2)
	CoreCommunicatorSetup t ccoms;
	mac1 = scnsl ->createCommunicator(ccoms);
	scnsl->bind(& t1,& t2,ch,bsb1,mac1);



Case study
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one instance of actuator should be placed in each zone
max……
User requirement
System View modeling
NW synthesis tool
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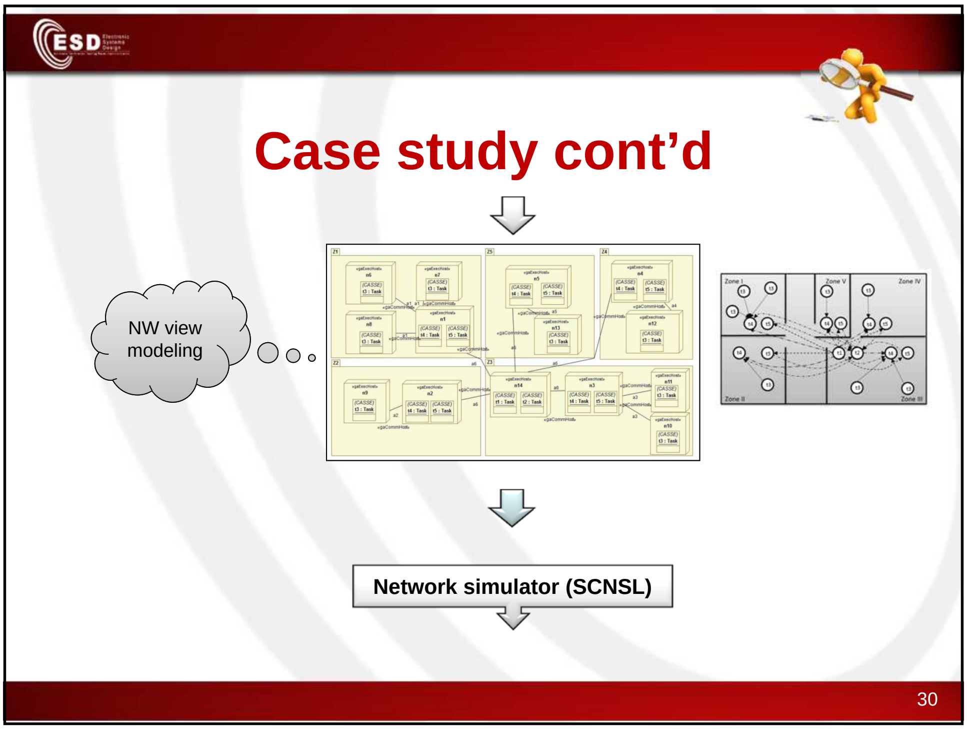

Case study cont'd
NW view modeling
Network simulator (SCNSL)
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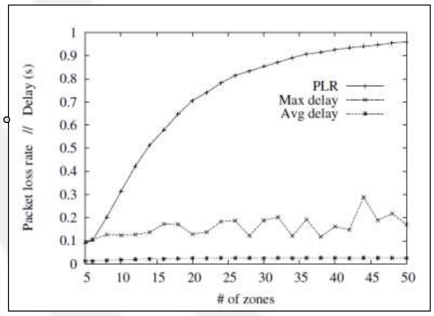
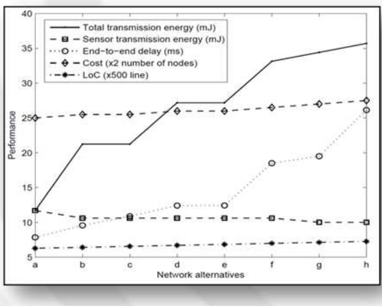
Case study cont'd

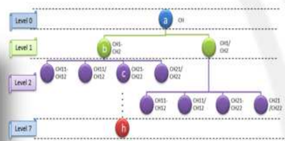
NW simulation statistics



Case study cont'd

NW simulation statistics





NW manipulation

Summarization

- User requirements and constraints has been modeled by using UML/MARTE profile and simulated by SystemC/TLM at system view level
- Simulation results has been used to refine the user model
- Network synthesis tools have been used to solve the application problem
- Network solutions have been modeled and simulated by using SCNSL
- Network statistics have been used for the final refinement of application model
- **M**anipulation and **A**utomatic design-space exploration

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Conclusions

- Some UML/MARTE diagrams and stereotypes have been used as a first time to represent the building blocks of a distributed embedded application
  - Elements from the MARTE specification have been applied to the context of distributed embedded applications
- Some gaps in MARTE standard have been identified concerning the representation of constraints and attributes related to error rate information
- SystemC code has been generated for both functional and network-aware simulation

A UML-centric design flow for networked embedded systems has been created

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