European Network on New Sensing Technologies for Air Pollution Control and Environmental Sustainability - *EuNetAir*

COST Action TD1105

A Holistic Approach in the Development and Deployment of WSN-based Applications and Systems

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Developing and Deploying WSNs

- Wireless Sensor Networks (WSNs) constitute a rapidly evolving networking area:
  - Environmental, health, security and industrial applications

different requirements regarding system performance and QoS

- Refer to different mechanisms, protocols, algorithms, HW:
  - Scheduling policies, OS, Security mechanisms
  - Routing and MAC protocols
  - Sensors, Actuators, Radio Tx/Rx

different levels of knowledge

- Employ special characteristics:
  - Constrained energy, CPU and memory resources
  - Multi-hop communication

special knowledge

Developing and Deploying WSNs

- Need for a boost to WSN widespread use:
  - User friendliness
  - Practicality
  - Efficiency

A tool integrating all appropriate features for the design of a WSN

- Evaluation, verification and guidance:
  - Critical features identification
  - Application requirements consideration
  - Design indications and suggestions

Need for profiling-modeling of SW-HW

- Long life-cycle, ease of WSN SW development:
  - Flexibility, extendibility, reusability

Componentizing SW

Desirable WSN features_Sustainability

- Low power consumption
  - Long operational lifetime for battery-powered unattended WSN nodes
- Joint optimization of connectivity and energy efficiency
  - Best-effort utilization of constrained radios in WSNs & min energy cost
- Self-calibration and self-healing
  - Recovering from failures and errors to which WSNs are prone
- Efficient data aggregation
  - Lessening the traffic load in constrained WSNs
- Programmable and reconfigurable stations
  - Allowing for long life-cycle development
- System security
  - Enabling protection of data and system operation
- Short development time
  - Short time-to-market for WSN systems
- Simple installation and maintenance procedures
  - Widespread use of WSNs

Outline

- The main contribution of the Industrial Systems Institute and the University of Patras to the ARTEMIS project WSN-DPCM focuses on:
    - *Middleware level*: seamless connectivity and interoperability issues over widely heterogeneous device and communication technologies,
    - *Development Tool level*: efficient hardware-in-the-loop simulation techniques and synthesis model evaluation modules, and
    - *Planning Tool level*: connectivity evaluation, critical node detection and links reduction modules

Middleware (1)

- Motivation:
  - Great "programming complexity gap" between development of WSN applications and appropriate handling of underlying system operation:
    - dynamic changes of the operational environment
    - different user-application requirements
    - heterogeneity
    - WSN operation specificities, resulting to special knowledge requirement
  - Application development turns to be a rather low-level programming procedure, resulting to:
    - relatively decreased energy efficiency and QoS, high resource consumption, time-cost
  - Lack of a unified basis of development to promote:
    - interoperability with other systems
    - reusability of implementations
    - system extendibility
    - system adaptation

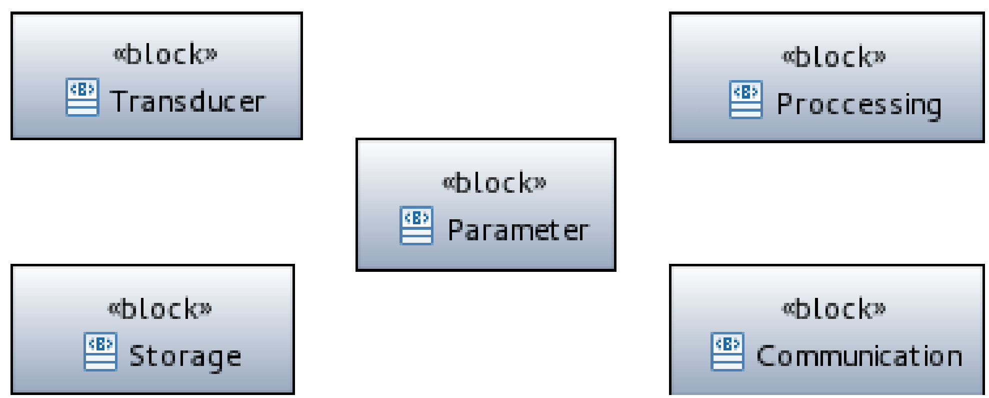
Middleware (2)

- Main Objectives:
  - Implement a middleware architecture which combines the state of the art in disjoint or loosely coupled research directions:
    - Adoption of a uniform MDE approach which maps well and through already existing standard notations and SW modeling constructs
    - Use of generalized high level application programming abstraction definitions
    - Deployment over a generative service/component execution framework, supporting both system and application component reconfiguration/reprogramming
    - Support of design-time and configurable run-time resource consumption awareness
    - Interoperability promotion based on mappings over existing international standards and industry driven specifications

Middleware (3)

- High-level Functional Abstractions:
  - Appear on top of lower level abstractions, which hide functionalities corresponding to platform and network interfaces:
    - CPU, memory storage, radio, network stack protocols
  - Encapsulate functionality of system or application level components:
    - Processing
      - representing application level algorithms and logic
    - Transducer (i.e. Sensors/Actuators), Storage, Communication
      - hiding underlying heterogeneity & corresponding access mechanisms
    - Parameter
      - defining the employed data model

application-level abstraction

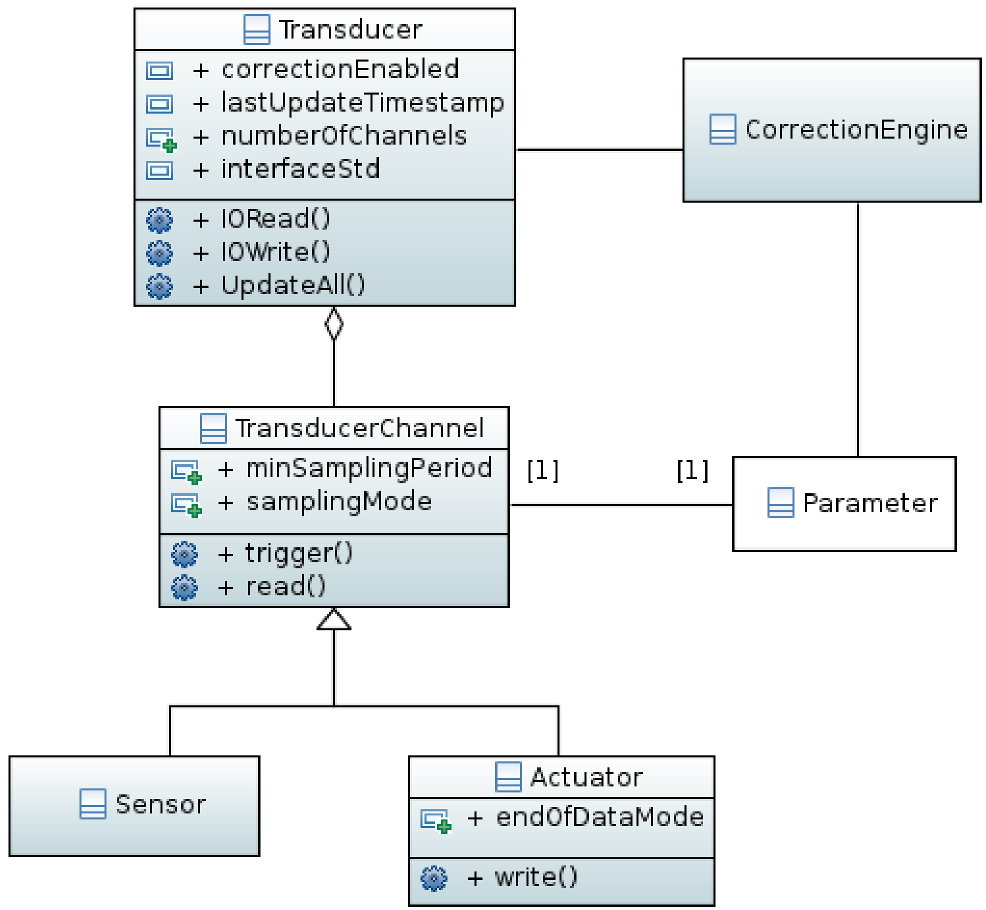


Middleware (4)

❖ IEEE-1451 compatible Transducer Framework:

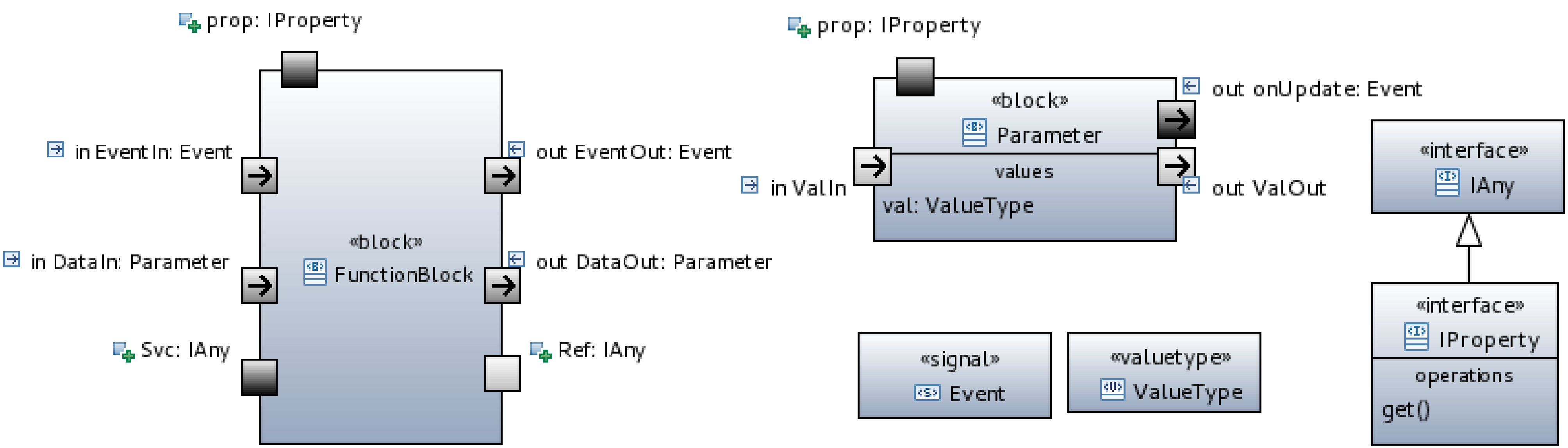
- Standard description of transducer's properties in a more generic/structured way
- Definition of common commands and functions to access transducers
- Correction engine performs further processing on measured transducer values

➢ Leading to short development cycles and easy integration of WSNs



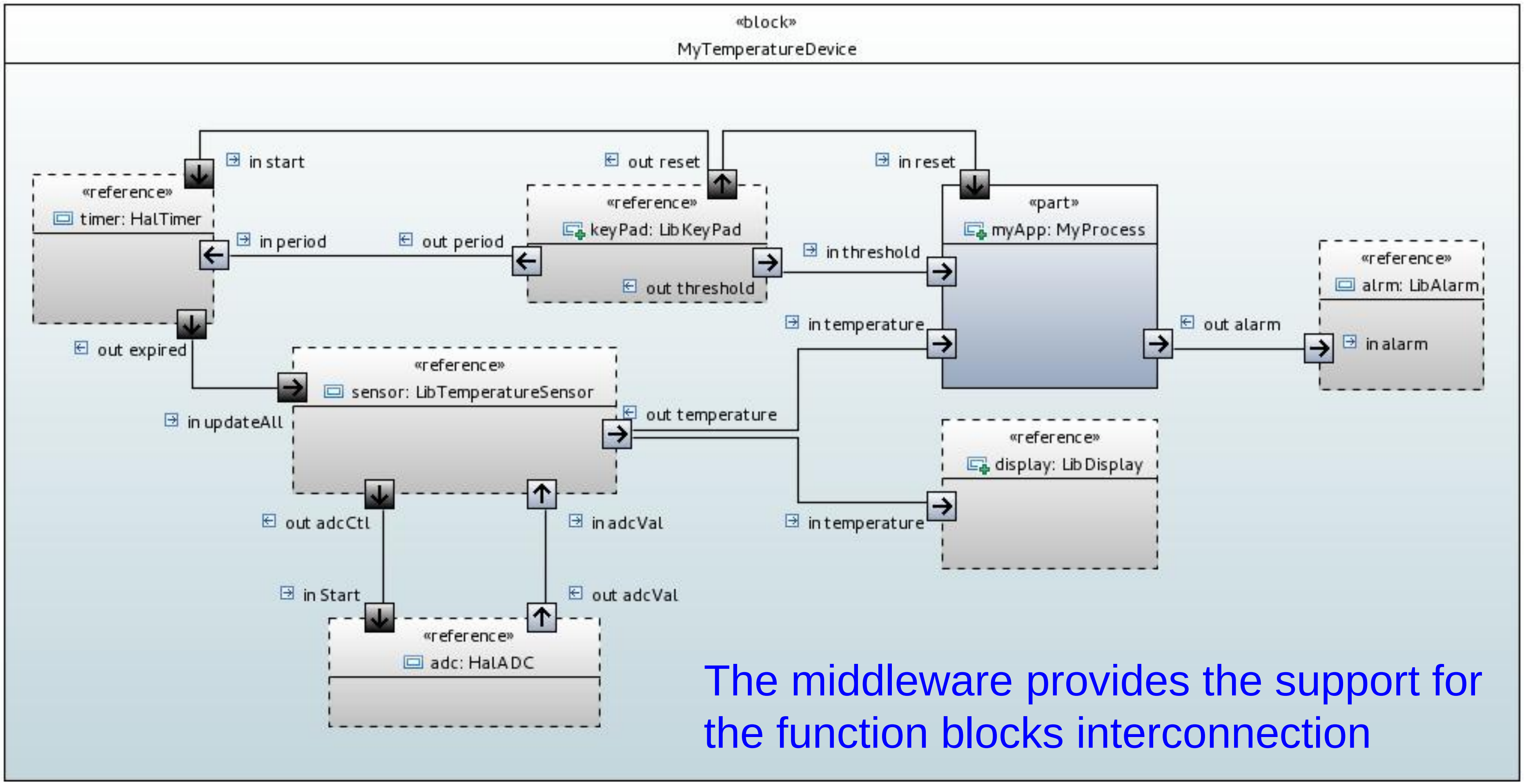
Middleware (5)

- Basic Component Framework supported by Middleware:
  - Combines CBD principles of accessing functionality implementations in composing WSN systems/applications through interface contracts:
    - IEC-61499: event-driven & data-flow process orientation
      - SysML flow ports representation
    - SCA: typical synchronous method for call semantics
      - SysML ports representation of service-reference-properties features



Middleware (6)

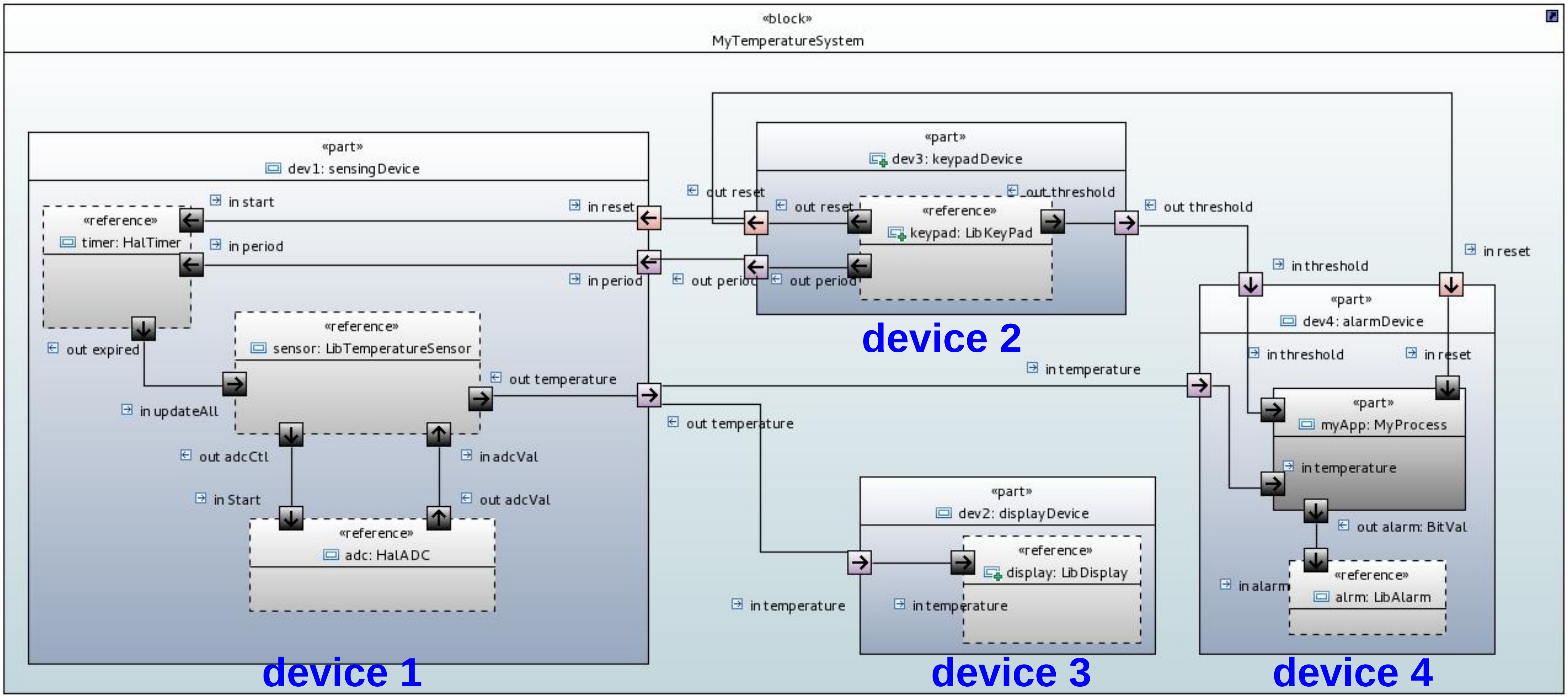
- Application development example (temperature sensing):
  - *Local node-level composition* of a simple application which:
    - Displays the current temperature in a local device
    - Turns-on an alarm when the temperature exceeds a threshold



The middleware provides the support for the function blocks interconnection

Middleware (7)

- Application development example (temperature sensing):
  - *Distributed composition* of the same simple application where:
    - Display, keypad, alarm and sensor parts exist on separate devices and exchange control and data seamlessly over the network



Development Tool (1)

❖ Motivation:

- Development of WSNs has not achieved adequate widespread use because:
  - In-depth knowledge is required at various levels: OSs, protocols, platforms, programming etc.
  - There are no fully integrated environments facilitating all phases of development: Design, Develop, Test, Validate, Maintain, Extend
- WSN Simulation study suffers from various shortcomings:
  - Lack of accurate models
  - Uncertainties of hardware influence to performance/behavior

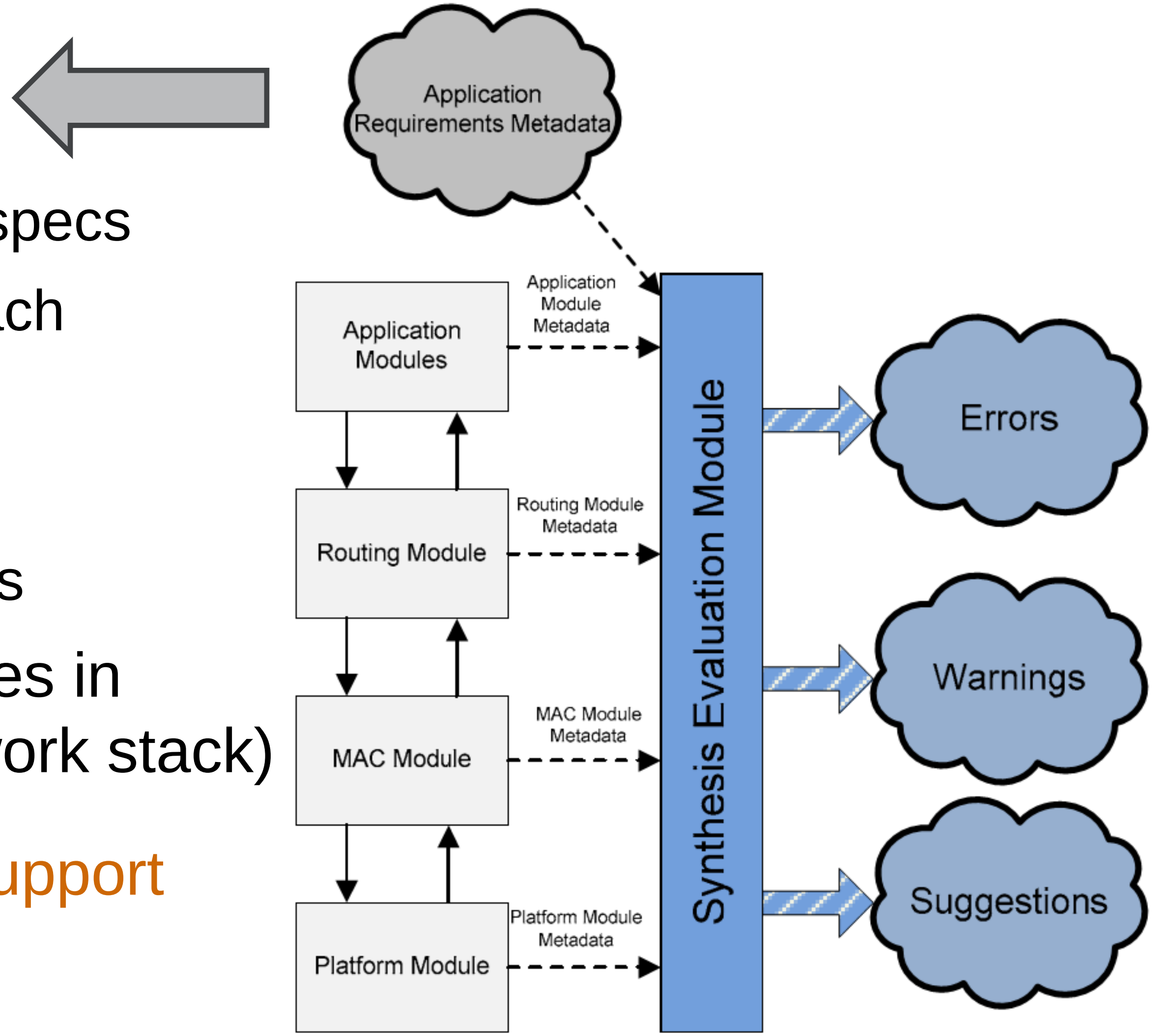
➢ Result: Inefficient cycles of development and unreliable power consumption estimation

Development Tool (2)

- Main Objectives:
  - Offer useful and practical tools enhancing the following aspects of DT for both experts and non-experts by means of Synthesis Evaluation Module (SEM)
    - Increase User-friendliness
    - Increase Efficiency
    - Decrease complexity
  - Offer Hardware-in-the-Loop techniques and propose approaches enhancing simulation-based features of prominent simulators
    - Increase simulation accuracy
    - Take hardware features into consideration
    - Accurate power consumption estimation

Development Tool (3)

- Synthesis Evaluation Module (SEM) Design:
  - Application Requirements:
    - Communication traffic specs
    - Communication approach
    - Node density
    - Packet loss
    - Real-Time requirements
  - Properties of SW modules in different levels (i.e. network stack)
  - Leading to substantial support of development process



Development Tool (4)

- Synthesis Evaluation Module Impact:

  Based on the User Choices and modules' properties correlation the SEM outputs indicate:

  - *Errors*:
    - Composition failures
    - Compatibility issues
    - Inconsistencies
  - *Warnings*:
    - Performance degradation
    - Operation failures
  - *Suggestions*: Indications leading to optimum SW stack
    - Concerning specific components/protocols configuration
    - Template SW synthesis based suggestion

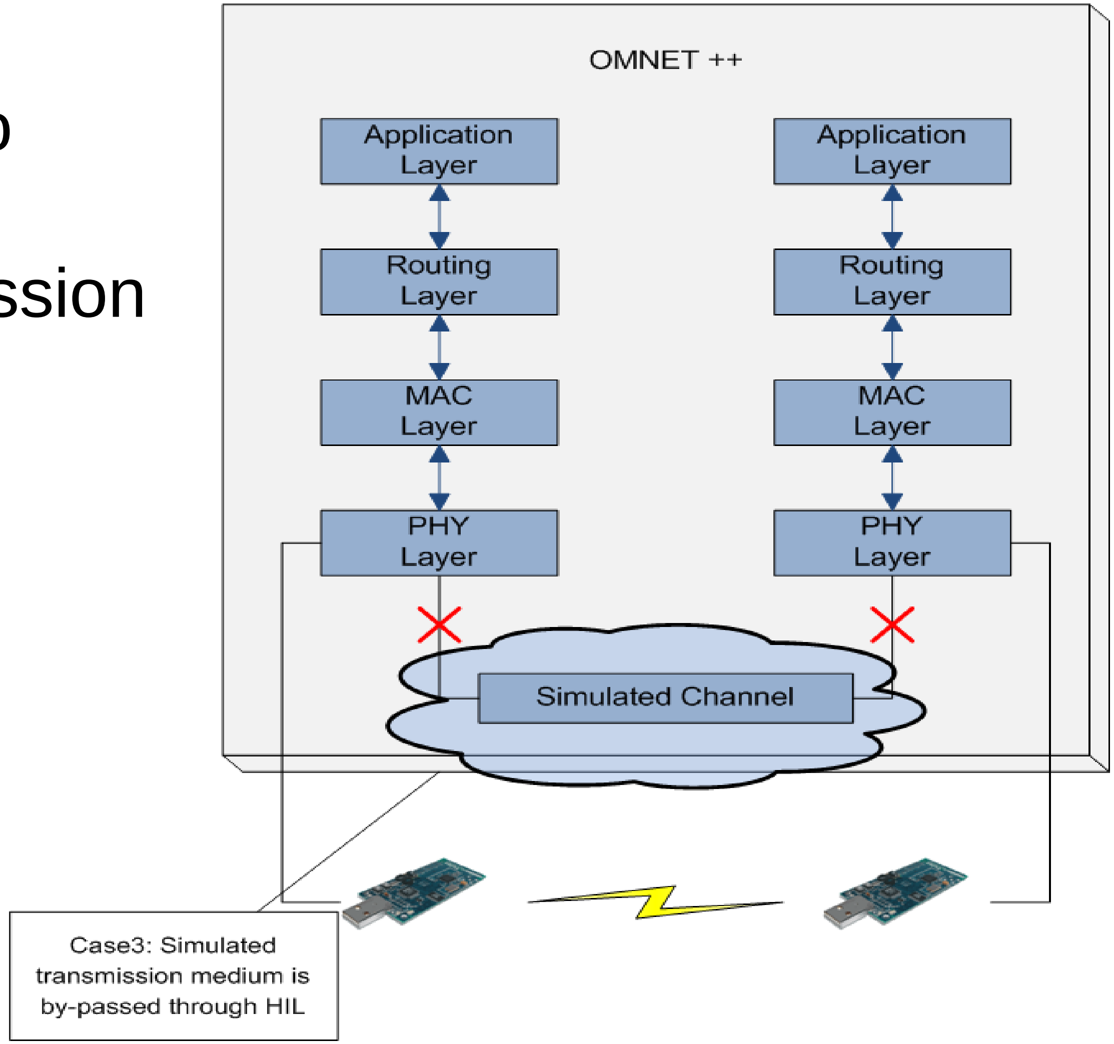
Development Tool (5)

- Hardware-in-the-Loop Rationale:
  - Integrate aspects of the a real WSN operation into dominant WSN simulation environments
  - Omnet++ is selected as one of the most prominent network simulator providing:
    - High modularity and flexibility
    - Component based architecture
    - Various WSN oriented frameworks focusing on different aspects
      - ✓ Castalia : Focusing on PHY layer mostly
      - ✓ MiXiM : Focusing communication protocols

Development Tool (6)

❖ Hardware-in-the-Loop Rationale: 1st Aspect

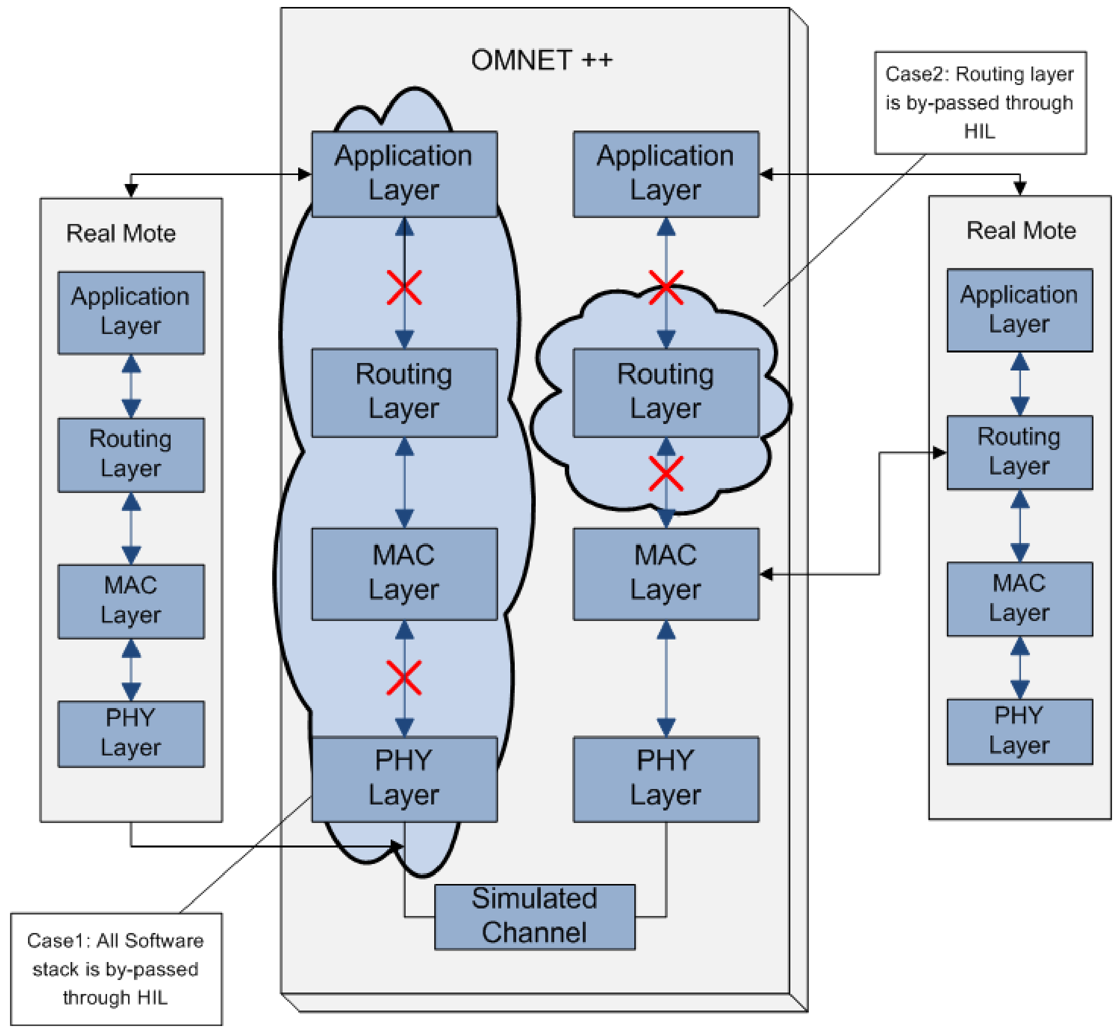
- Simulation taking into consideration
  real wireless transmission characteristics



Development Tool (7)

❖ Hardware-in-the-Loop Rationale: 2nd Aspect

- Simulation taking into consideration processing capabilities



Deployment: Planning Tool (1)

- Motivation:
  - WSN deployment provides answers to fundamental issues:
    - Number of nodes needed to meet overall system objectives
    - Deployment of these nodes to optimize network performance
    - Adjustment of network topology and sensor node placement in case of changes in data sources and network malfunction
  - WSN simulation suffers from various shortcomings:
    - Insufficient propagation models in terms of environmental parameters and WSN hardware variations
    - ➢ Leading to inaccurate positioning and link quality estimation
    - Lack of accurate energy models
    - ➢ Leading to inaccurate energy-waste-per link and overall network lifetime estimation.

Deployment: Planning Tool (2)

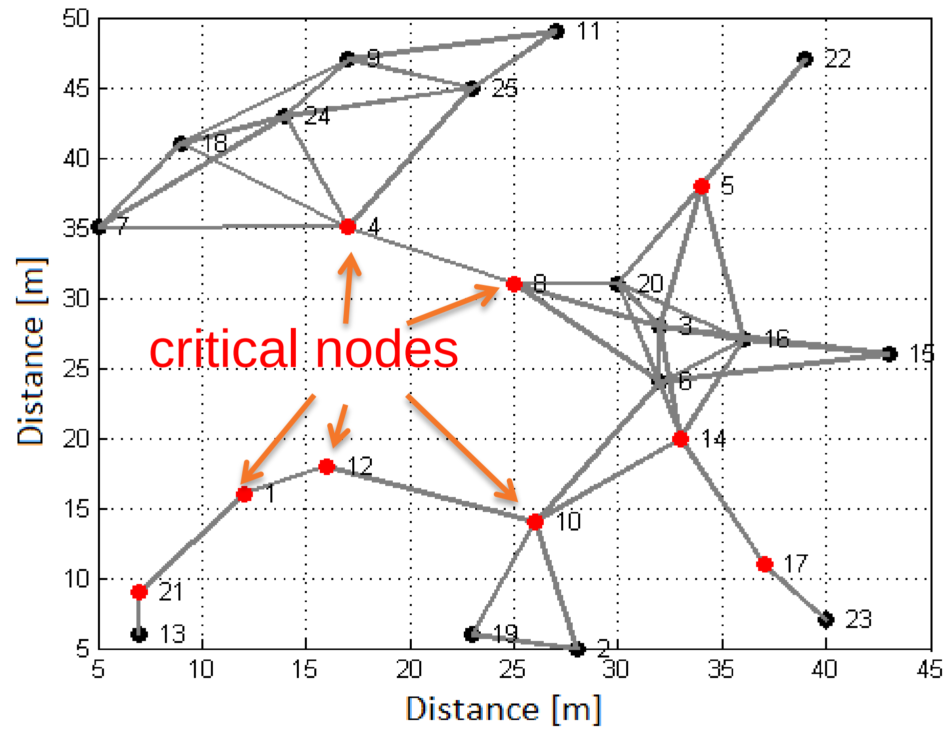
- Main Objectives:
  - Dominant deployment objectives:
    - Optimal sensing coverage of an area
    - Realistic representation of signal propagation considering all environmental and HW particularities
    - Optimal and energy efficient connectivity
    - Construction of network topology based on application-driven network requirements
    - Simple installation and maintenance
  - Of paramount importance are the aspects of:
    - *Connectivity*: seamless capability of getting data from the source to the appropriate destination
    - *Topology*: nodes and links that allow direct communication

Deployment: Planning Tool (3)

- Connectivity evaluation and identification of critical nodes:
  - *Critical nodes* determine the reliable operation of the network, since possible malfunction or removal leads to partition
  - Connectivity evaluation algorithms encompassing:
    - ✓ the Algebraic Graph Theory (AGT) approach: representing network topologies as graphs and using linear algebra and matrix theory
    - ✓ the Depth First Search (DFS) approach
- Topology control:
  - Generate initial network topology based on application requirements
  - Evaluate reduced topology alternatives, preserving the connectivity and taking into account the communication overhead
  - Topology control algorithms based on: Minimum Spanning Tree (MST), transmission power and neighborhood exploitation

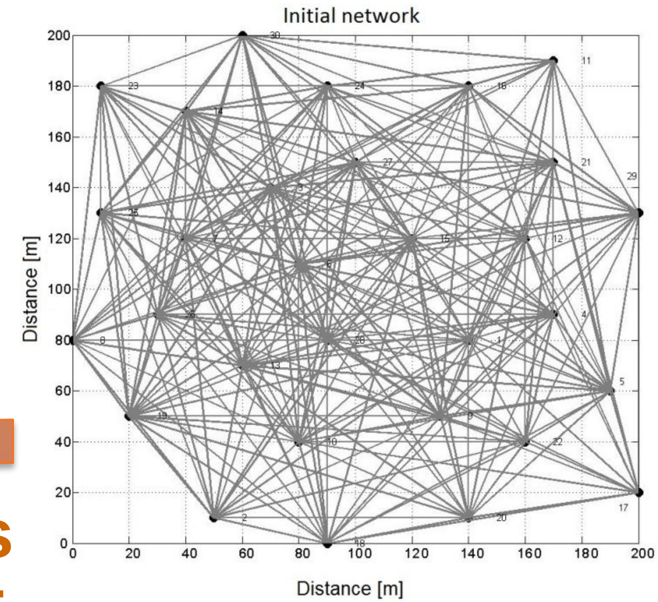
Deployment: Planning Tool (4)

- Connectivity evaluation example:
  - Input:
    - Area size: 50m x 50m
    - Number of nodes: 25
    - Tx power: 0dBm
    - Height from the ground: 0.1m
    - Propagation model: 2-ray ground based
  - Output:
    - Status of the network: connected
    - Number of critical nodes: 9
      - Node IDs: 1, 4, 5, 8, 10, 12, 14, 17, 21

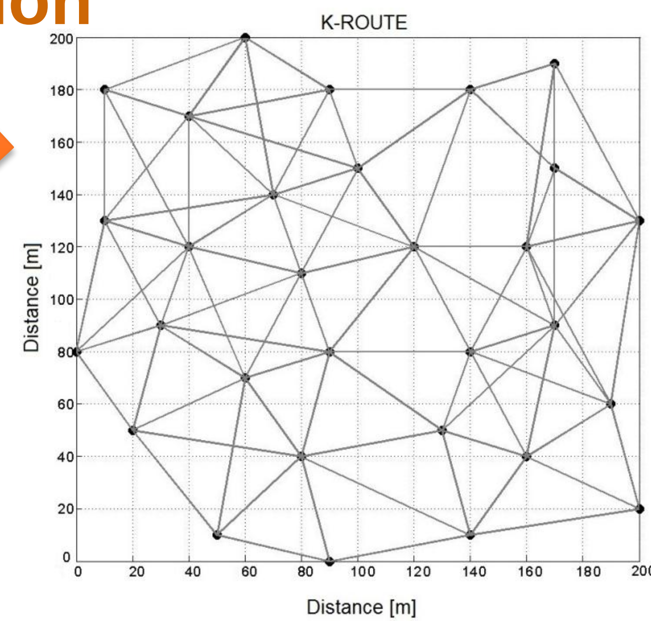


Deployment: Planning Tool (5)

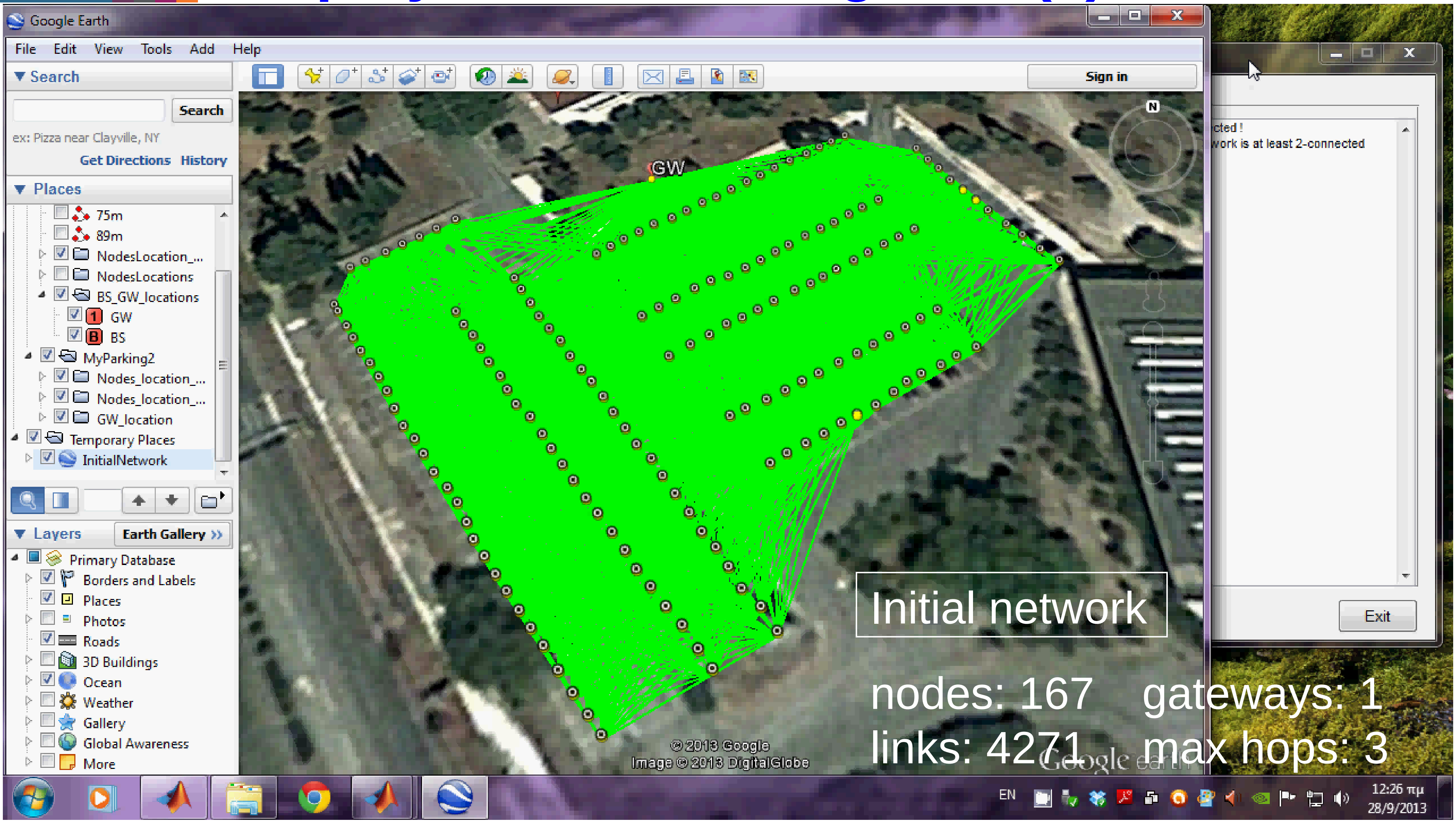
- Topology control example:
  - Initial topology:
    - Number of nodes: 30
    - Number of links: 582
    - Avg number of neighbors: 19
  - Reduced topology:
    - Number of nodes: 30
    - Number of links: 174
    - Avg number of neighbors: 6
  - System performance benefits:
    - Less contention, collisions and power waste



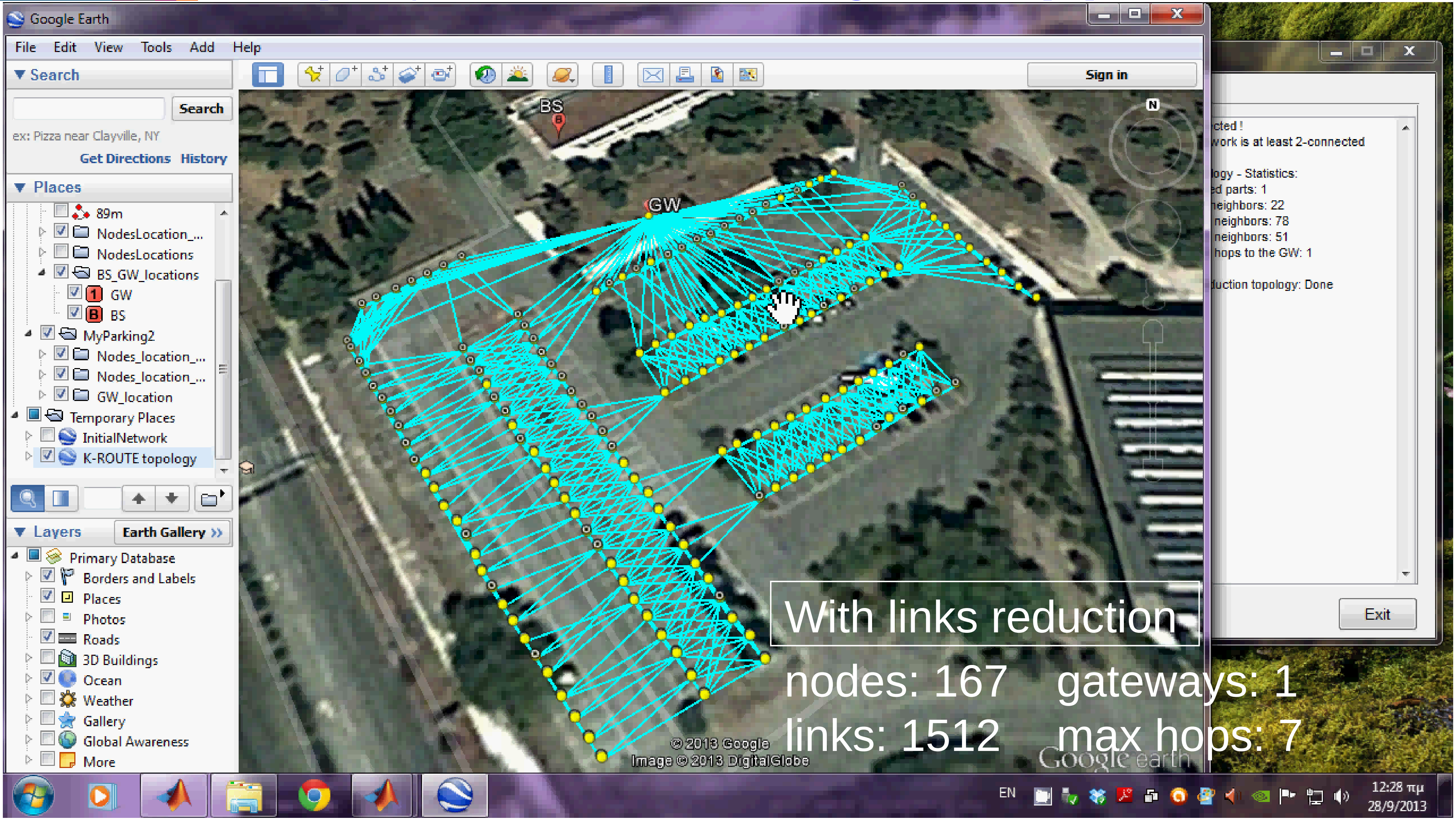
links reduction



Deployment: Planning Tool (6)



Deployment: Planning Tool (7)



Thank you for your attention.

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Abbreviations

- *MDE* : Model-Driven Engineering
- *SCA* : Service Component Architecture
- *CBD* : Component-Based Development