MODELLING RELIABILITY OF SMART GRID SERVICES WITH STOCHASTIC REWARD NETS

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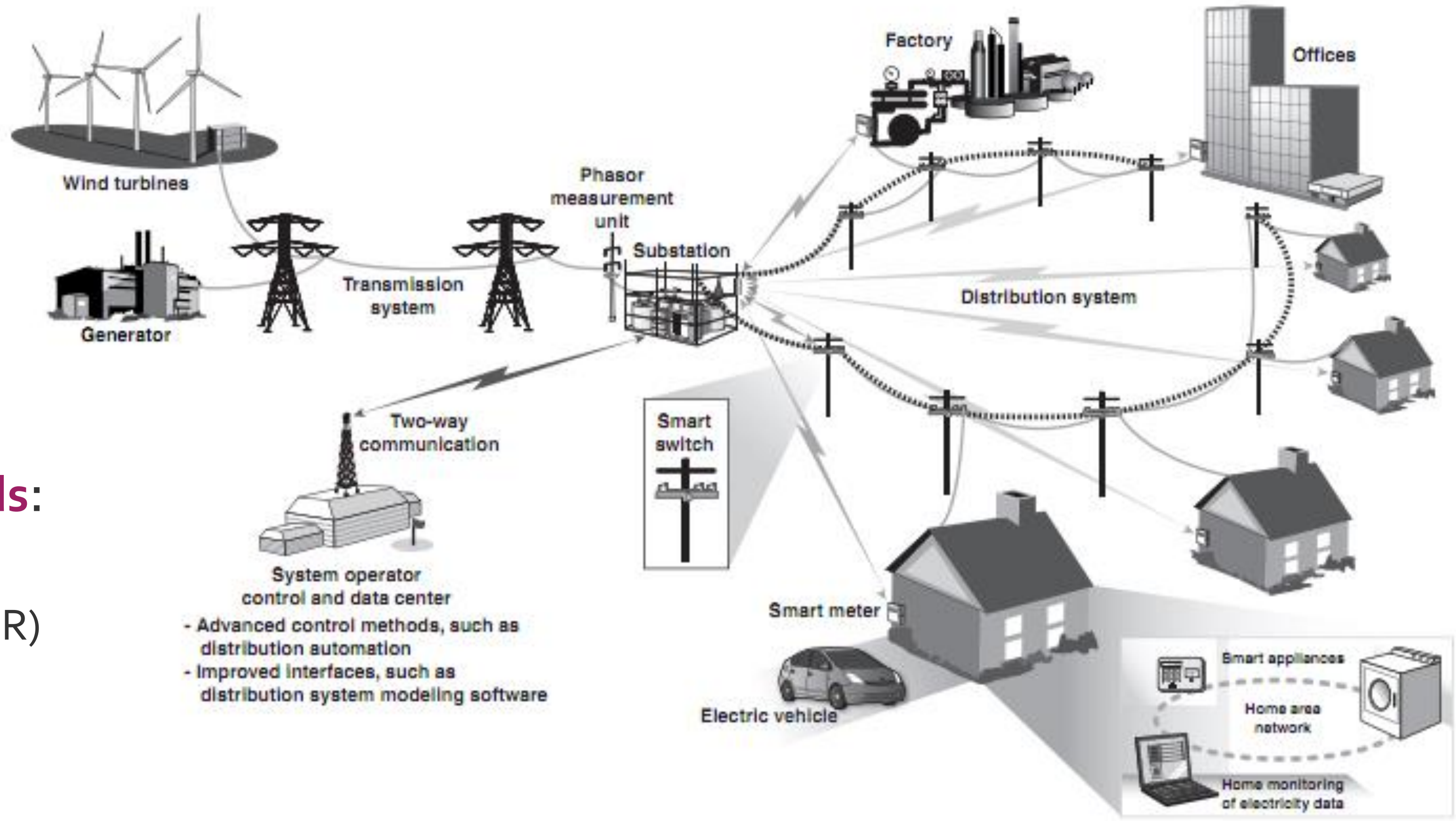
RELIABILITY IN SMART GRIDS

Smart Grid

- **Smart grid** is an electricity network that employs innovative products and services together with intelligent monitoring, control, communication and self-healing technologies.
- Challenges of **legacy power grids**:
  - Uninterrupted power supply
  - Distributed energy resources (DER)
  - Load management
  - New types of electrical devices



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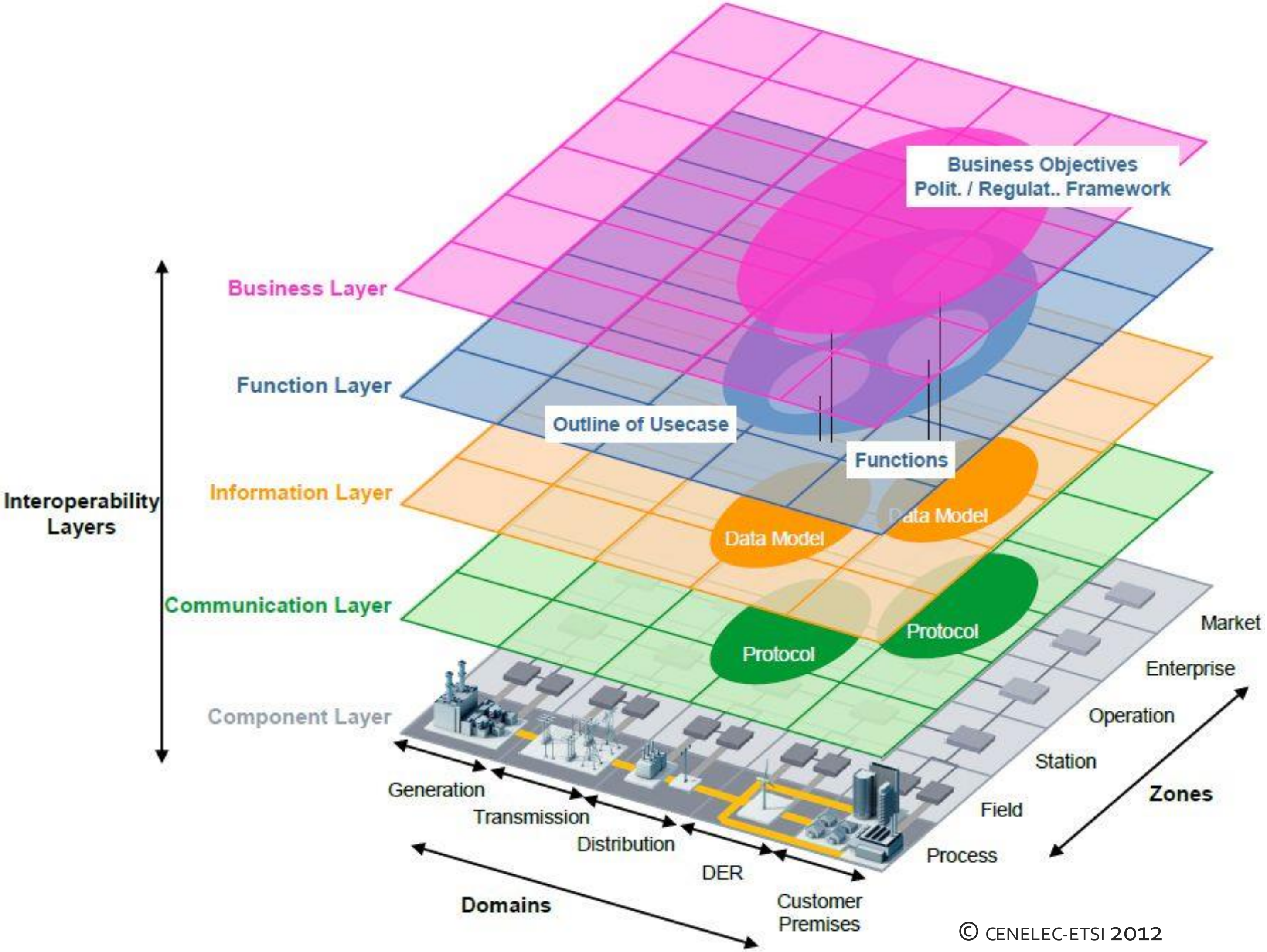
Smart Grid Reference Architecture



Smart Grid Reliability

- Power (smart) grid is considered a **critical infrastructure**
  - High requirements for reliability
  - Close relation to security, adequacy, availability, survivability and resilience
- Understanding of reliability varies between grid layers
  - **Communication**
    - fraction of time a service is available, fraction of successfully delivered packets, packet delivery latency,…
  - **Distribution**
    - SAIFI, SAIDI, CAIDI, …
- **Loss of load** probability

Existing Approaches for Reliability Analysis

- Reliability engineering
  1. Reducing the likelihood or frequency of the failure.
  2. Identification and correction of the causes of the failures
  3. Dealing with occurred failures
  4. **Estimating the likely reliability of new designs and analysis of reliability data**
- Most of the reliability-related effort focus on
  - Fault-tolerance, fault-prevention and failure-recovery
- Reliability estimation methods for (smart) power grids consider **physical layer only**.
  - Probability of blackouts
  - HW and communication links failures
- **Missing** evaluation of failures in **software components**.

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Existing Approaches for Reliability Analysis

- Perception of the reliability in the smart grid systems should expand also to **other layers** and to **additional failure types**
- Not all failures in smart grid must result in blackout
- E.g. a **Billing use case**
  - There might be a failure during the reading of the smart meter
    - Incorrect consumption data => wrongly calculating the price for power consumption.
  - Such failure does not cause a power outage
    - Might have negative impact on the associated stakeholders
    - Possible impact on other use-cases (e.g. load management algorithms).

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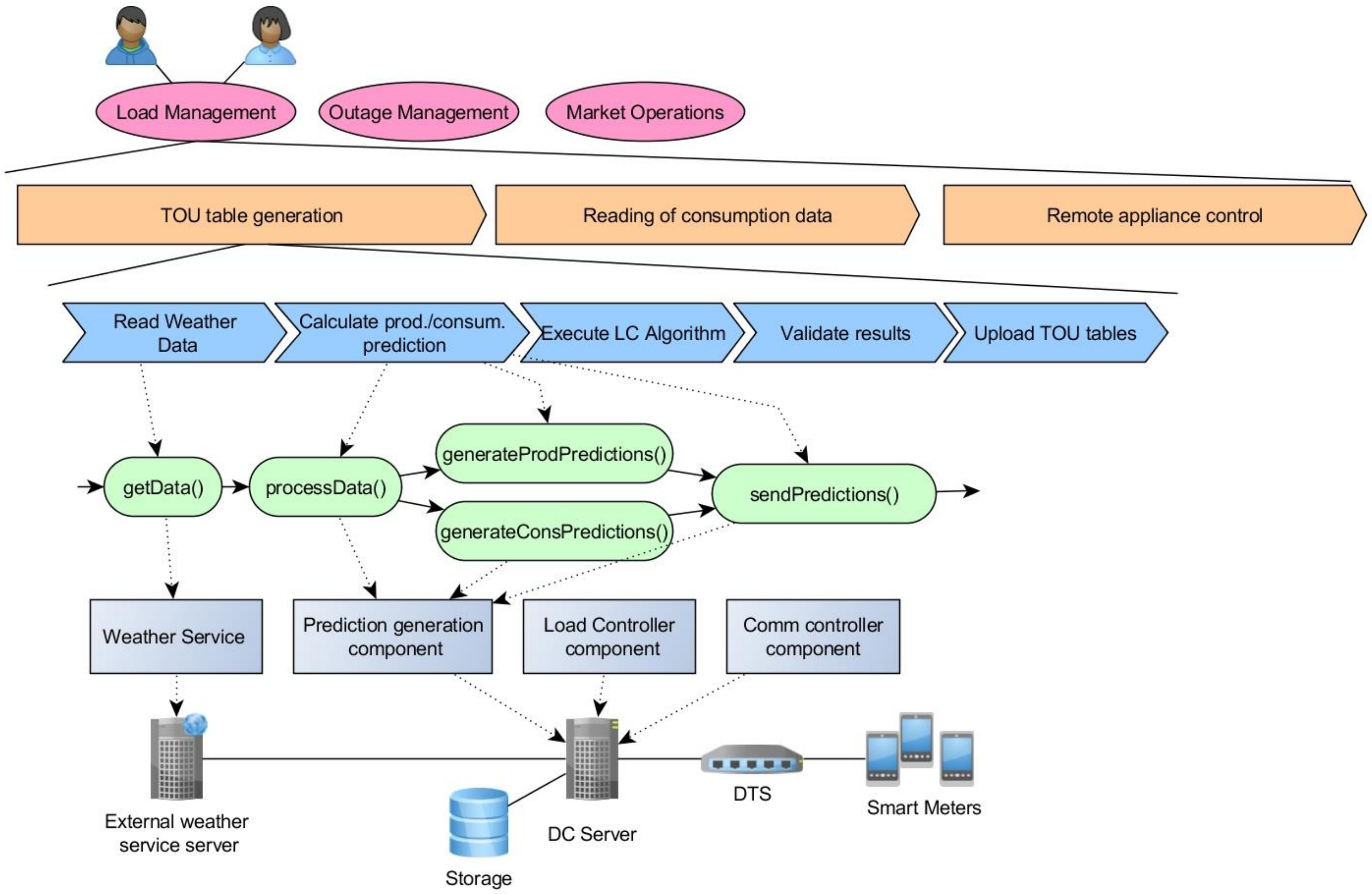
Aims of my research

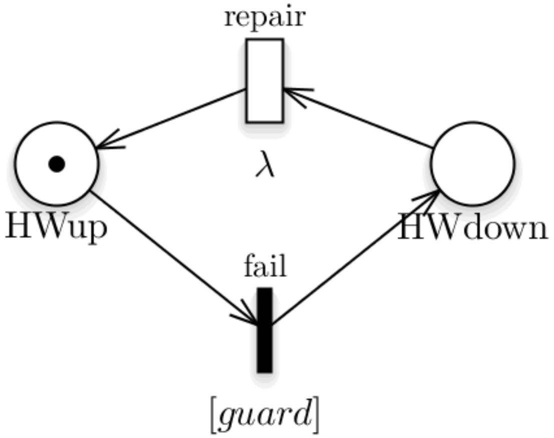
- **Multi-layered** approach for the reliability analysis of a smart grid infrastructure.



PETRI NETS/STOCHASTIC REWARD NETS

Stochastic Reward Nets

- Stochastic Reward Net(SRN) is a special case of PN with several extensions. The most important are
  - **Timed** and **Immediate** transitions
  - Transition **guards**
  - **Reward functions**



- The SRN is transformed into **Markov Reward Model**, which is then solved to provide reliability, availability and performance related measures
- Typical output measures are
  - Pmf of number of tokens at given place
  - Expected number of firings of transitions (throughput)
- Multiple reward functions can be defined for the same net topology

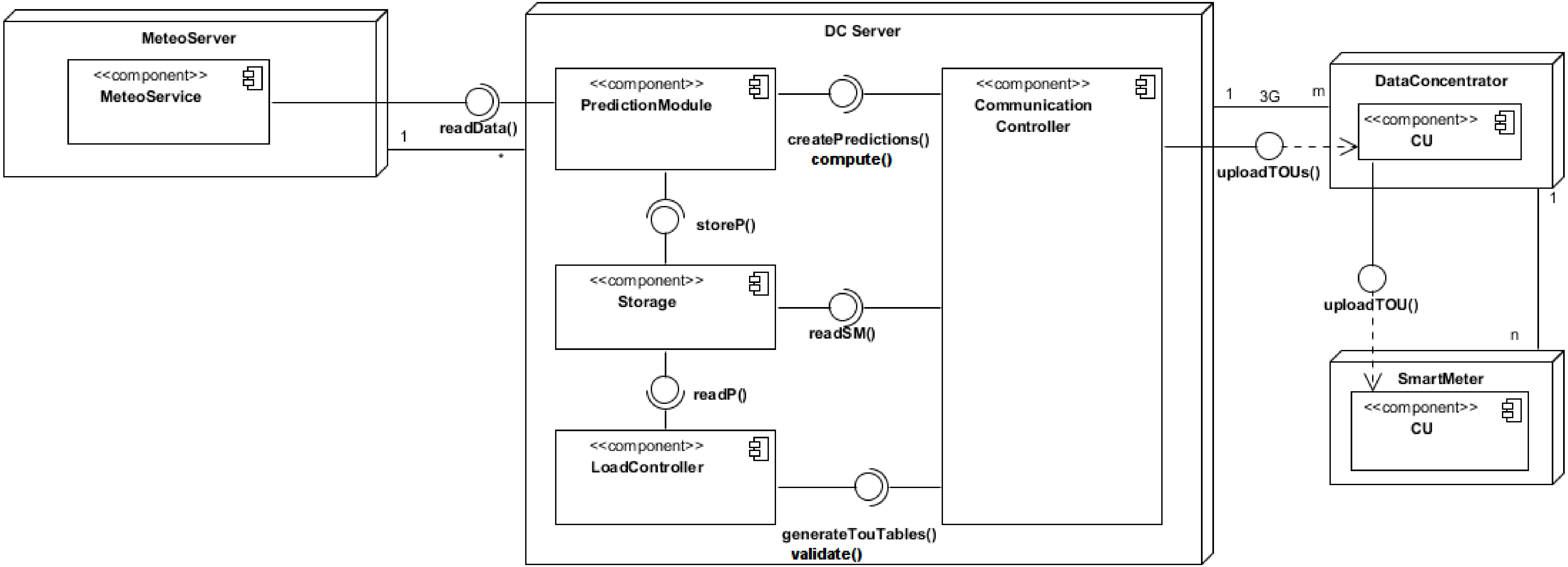
MULTI-LAYERED RELIABILITY MODEL

SRN Model

- Supported layers
  - Physical layer
  - Software/Service layer
  - Communication layer
  - Energy layer
- Will be generated from the annotated UML models (deployment and sequence diagrams)
- Usage/Service layer is hierarchically decomposed into multiple levels
- Connection between levels via guard conditions
- Integration of communication link failures
- Modelling of large number of devices
- Hardware and software failures with dependencies

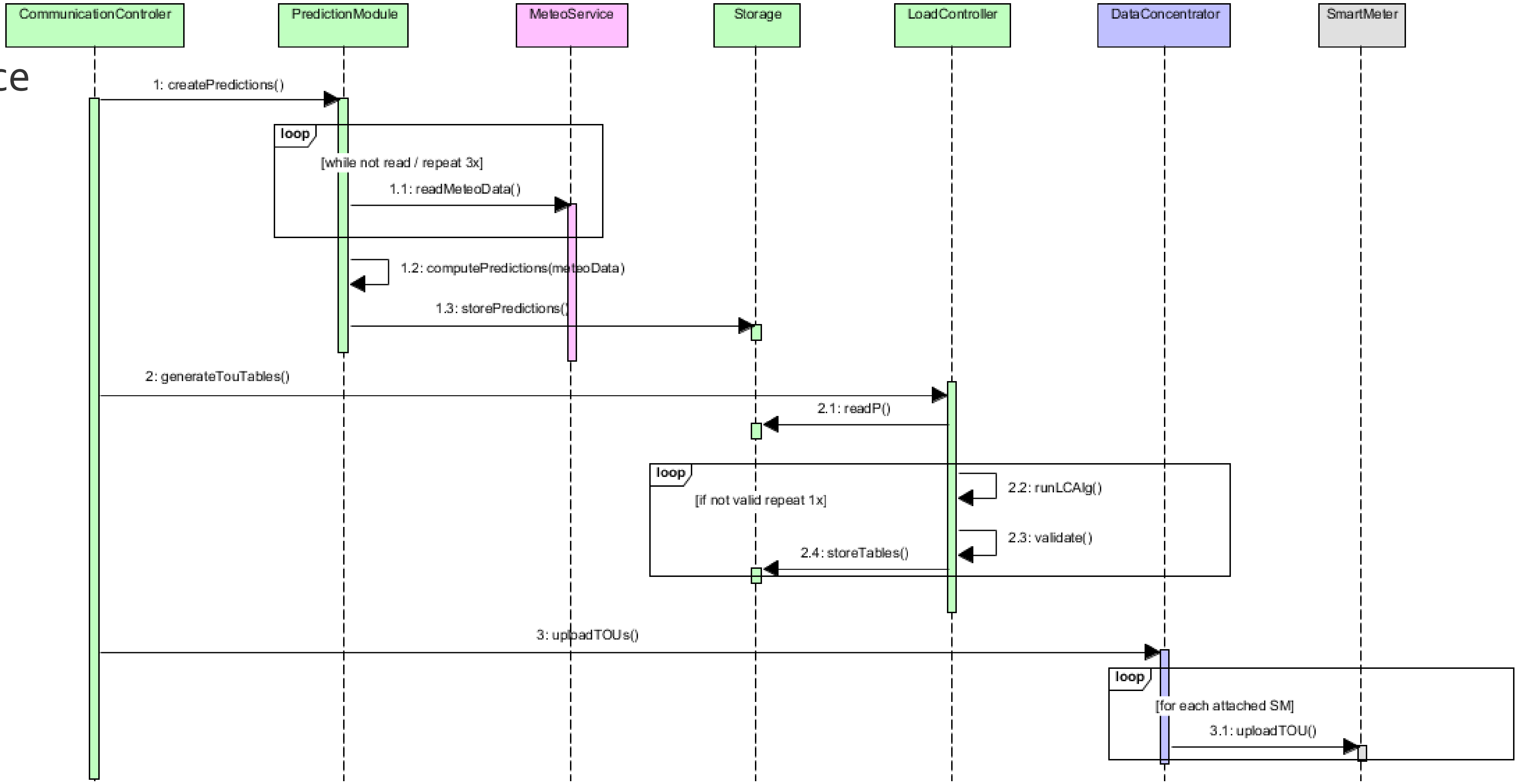
TOU Table Generation and Upload Scenario

- Deployment diagram



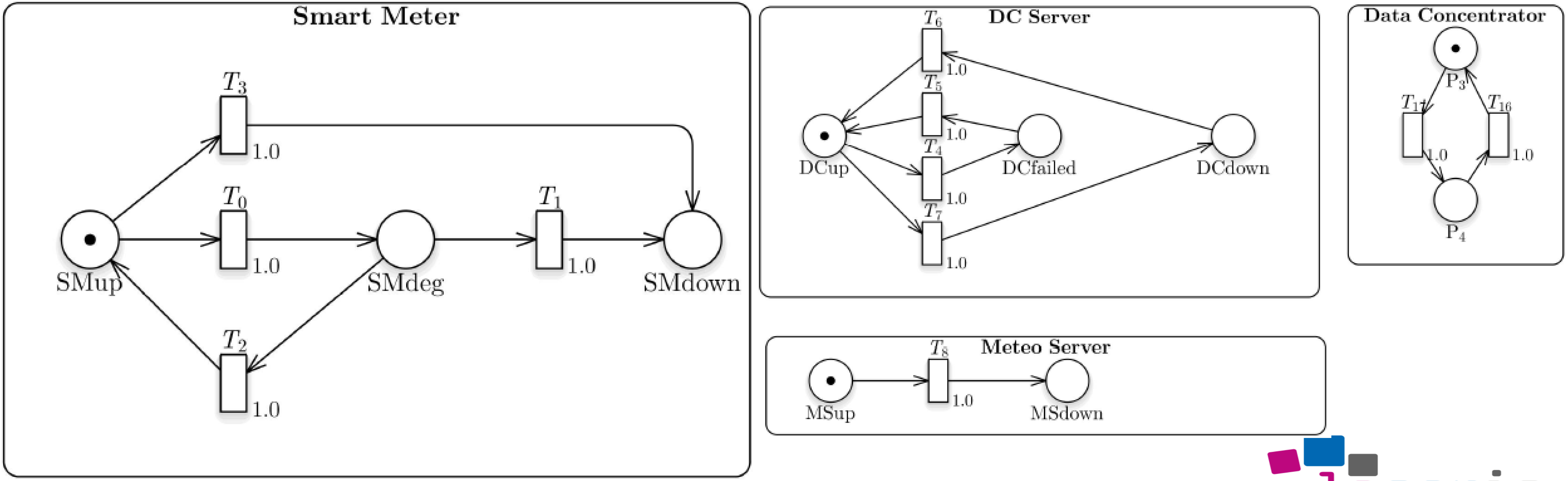
TOU Table Generation and Upload Scenario

- Sequence diagram



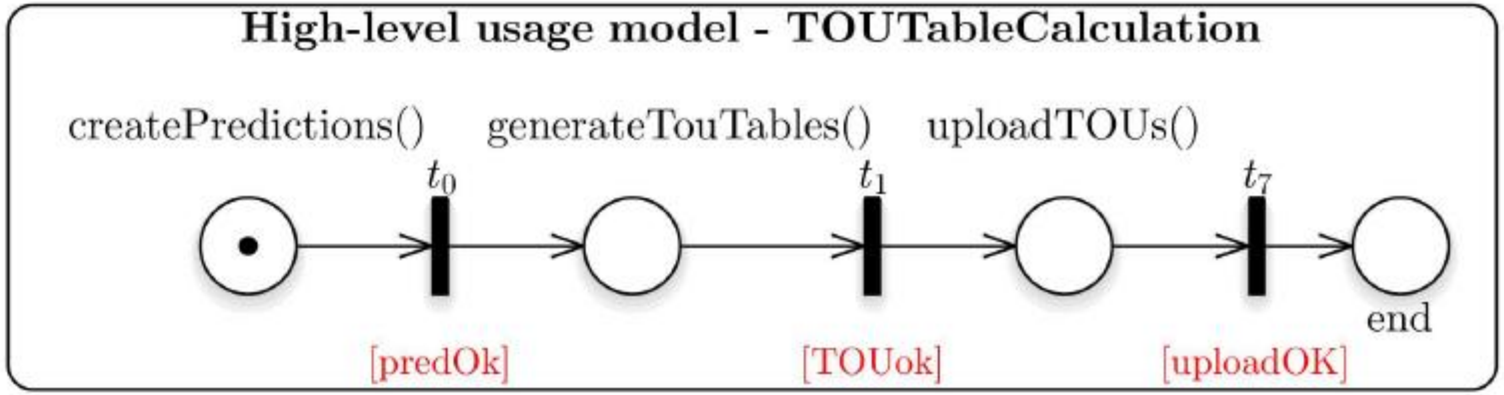
Hardware/system model

- Support for failure and degraded service states.
- Connected to service models through guards



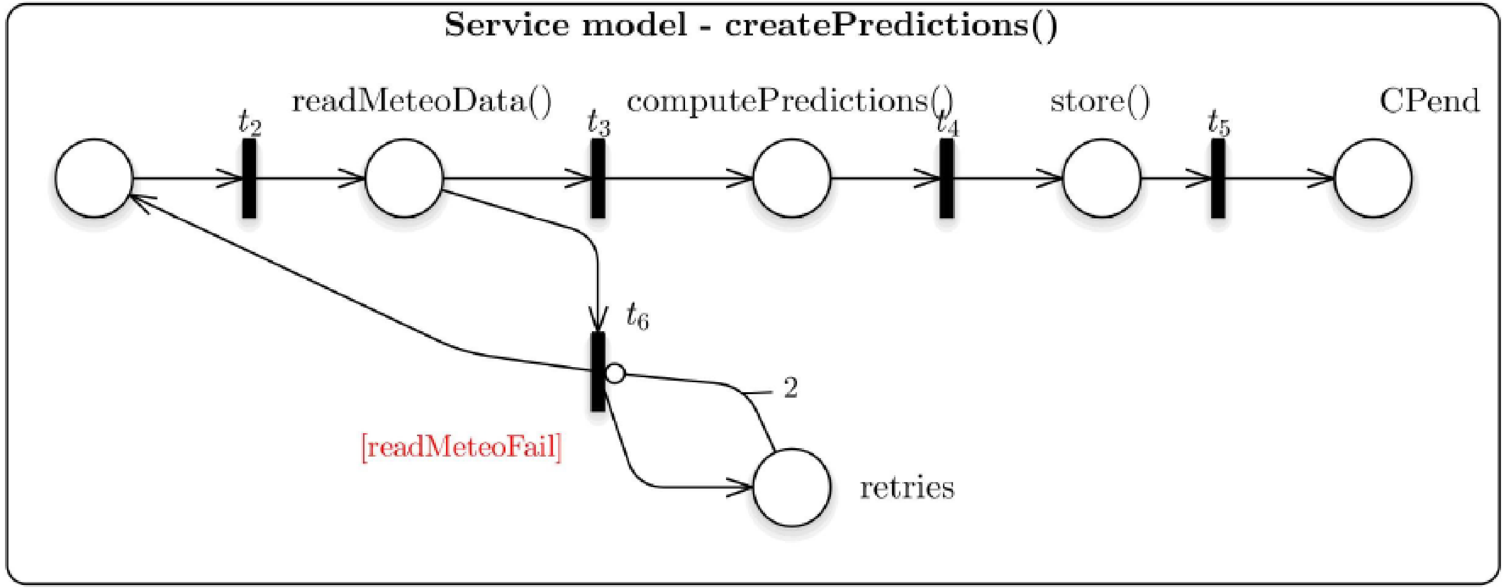
High-level usage model

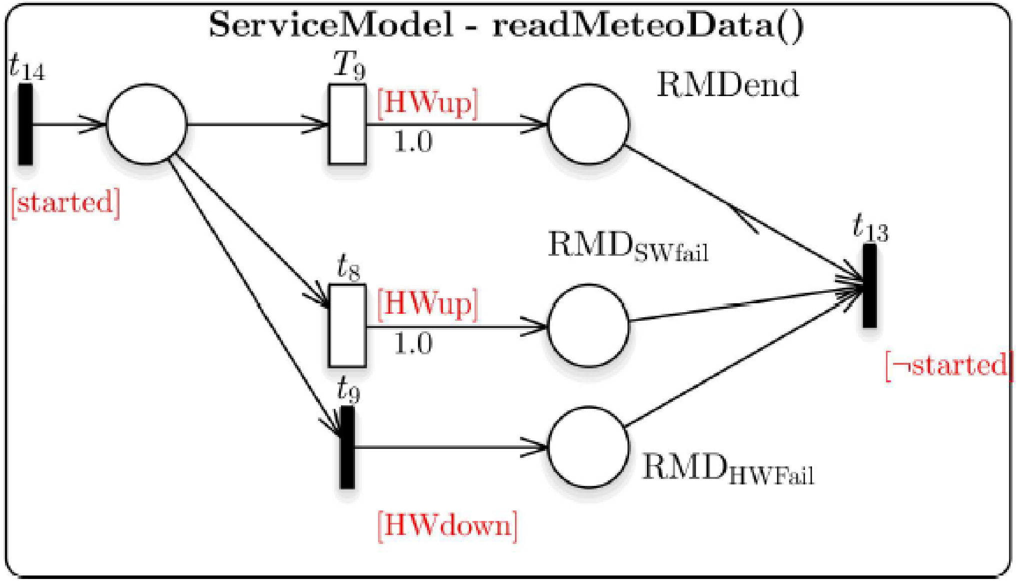
- Contains methods/service calls from the actor
- The immediate transitions are enabled by successful completion of the previous operation



Usage model - service level

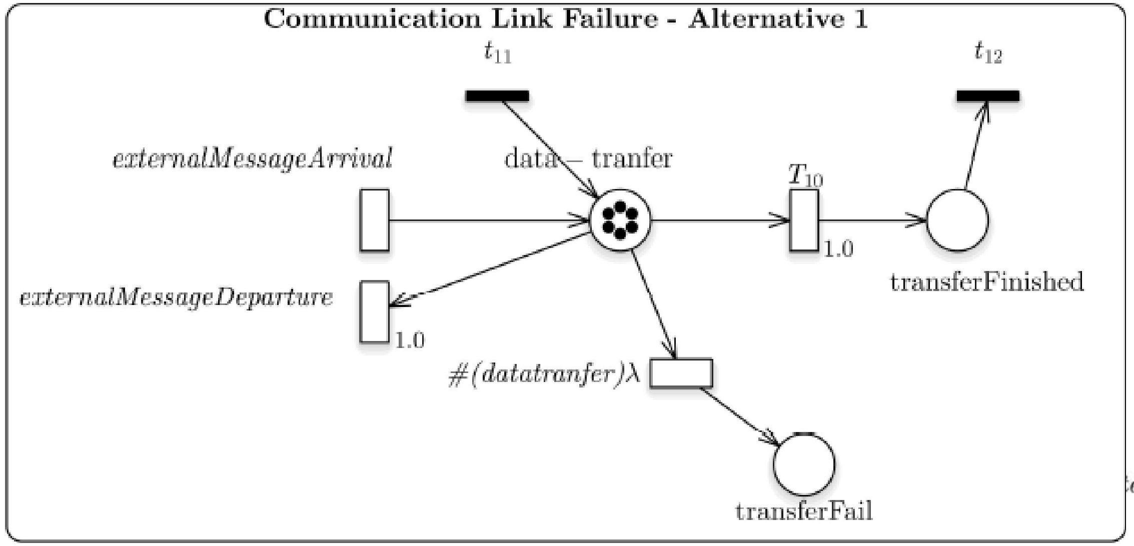
- Represents behaviour of the service/method calls
- Can contain other service/method calls or internal processing actions
- The internal actions depend on the availability of the required HW resources
- Can model different types of failures (hw, sw) and recovery mechanisms.

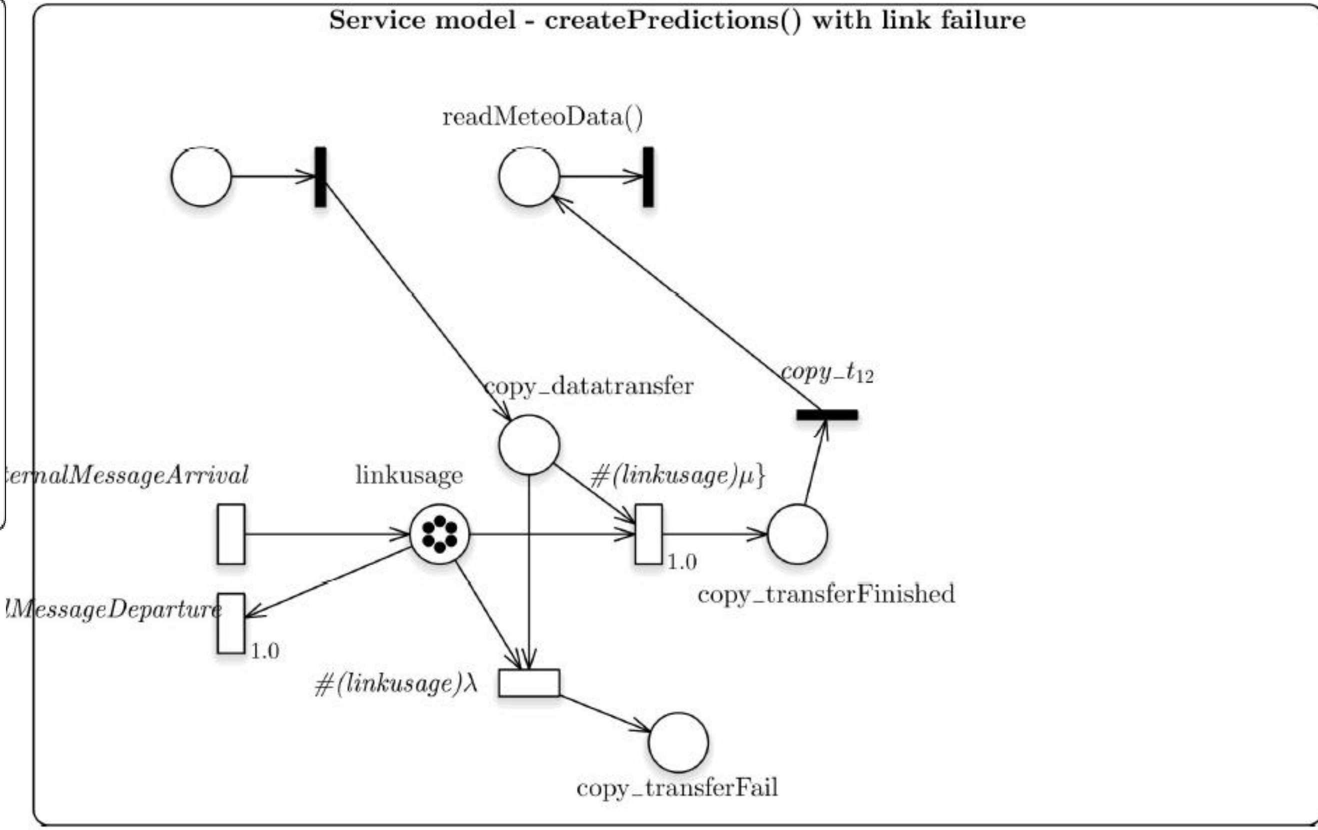




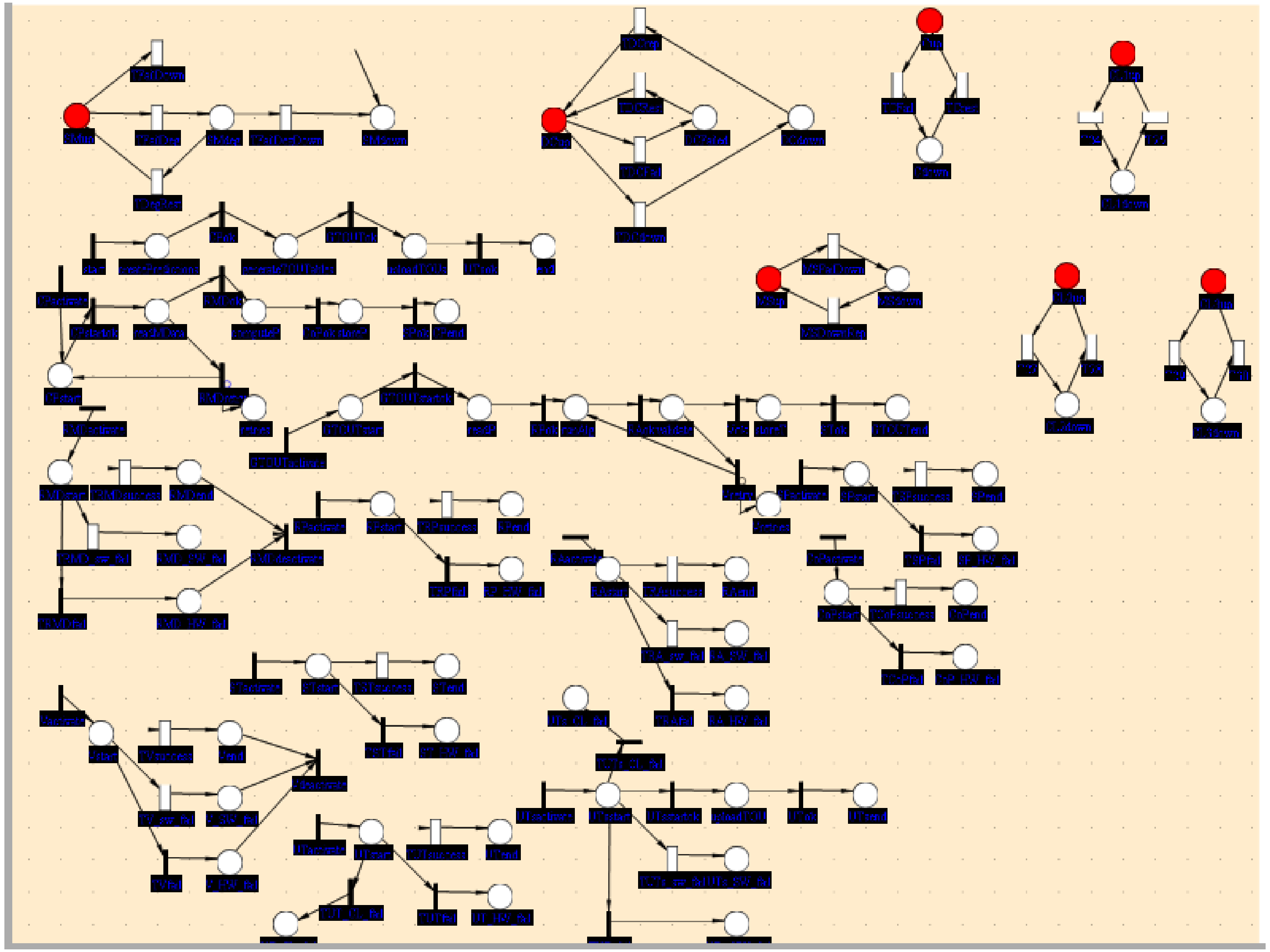
Communication link failures

- Inserting communication segment into a service model





Scenario – SPNP implementation



- SRN
  - 67 places
  - 41 immediate transitions
  - 30 timed transitions
  - Guards on most transitions
- Reachability graph/CTMC
  - 17 760 markings
  - 140 177 transitions
  - Analysis time – 3s

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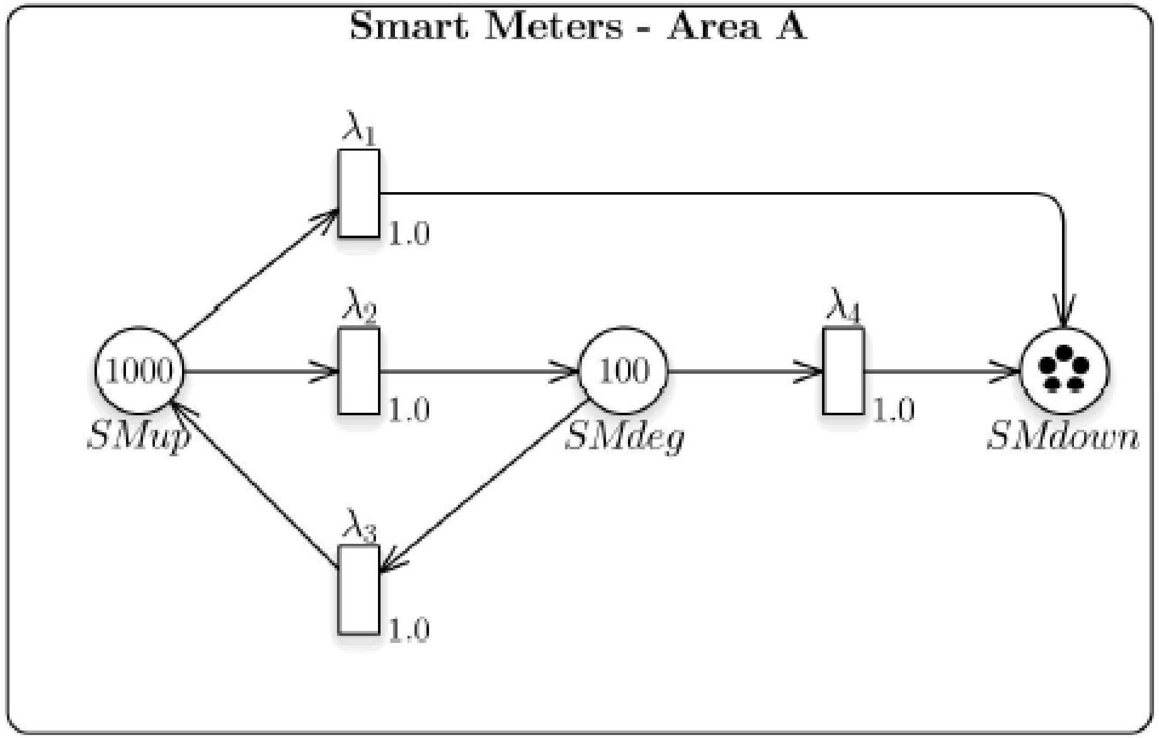
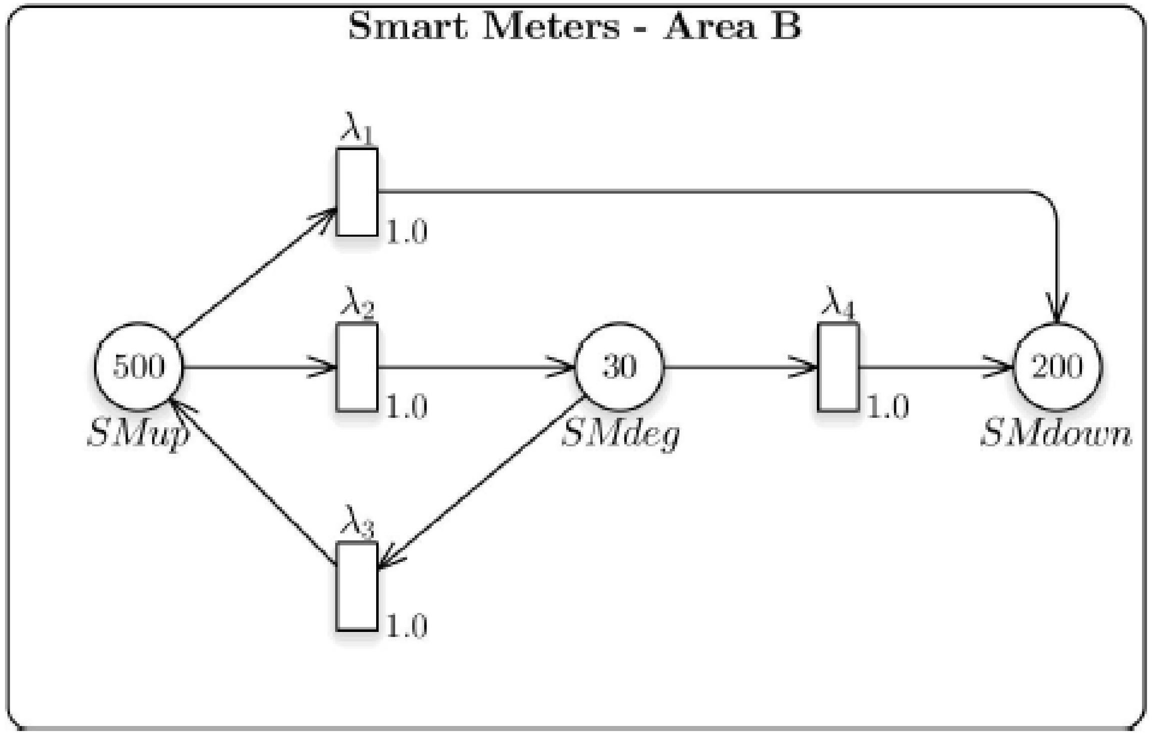
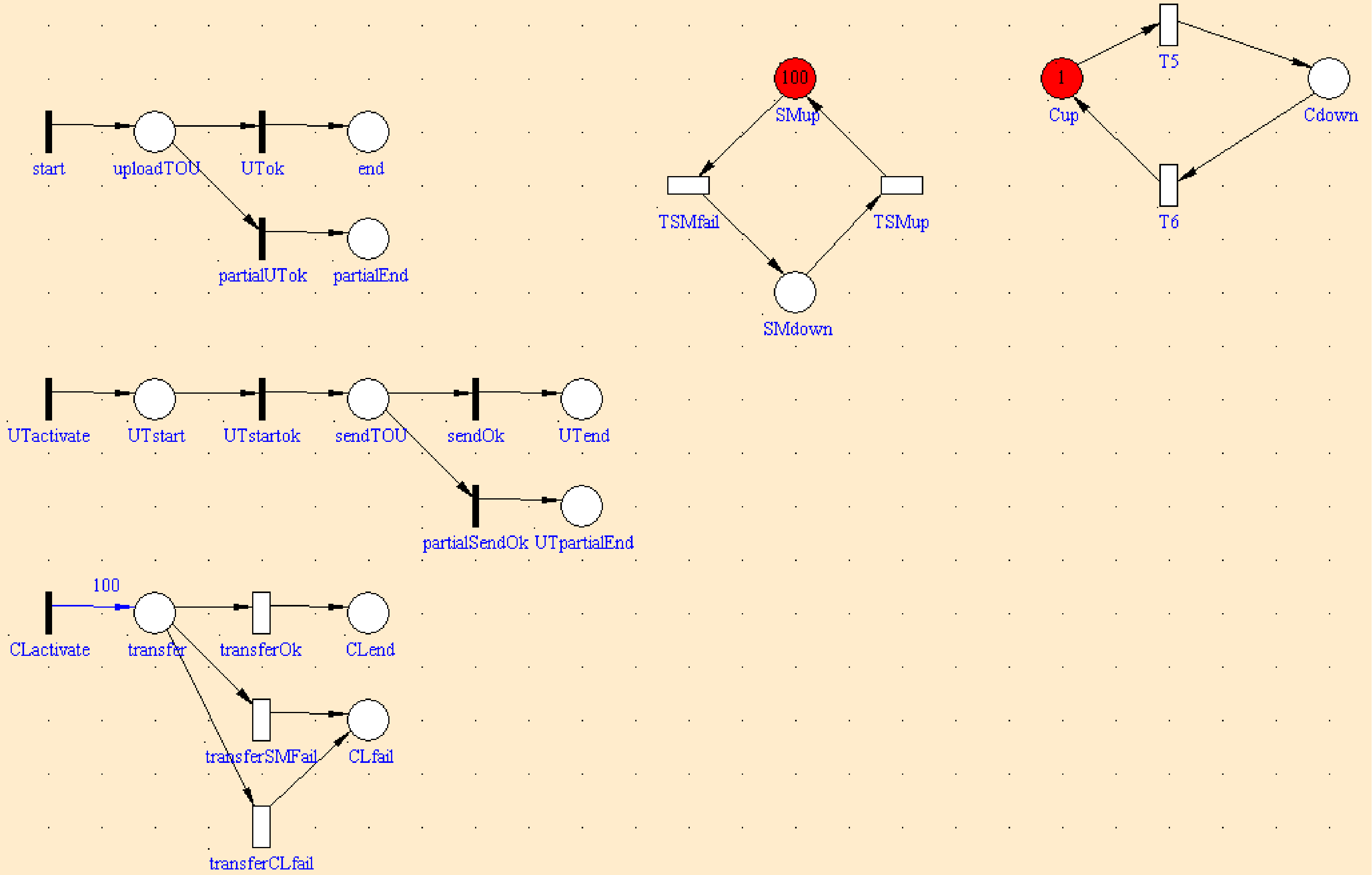
Large number of devices

- The devices are represented by tokens instead of nets.



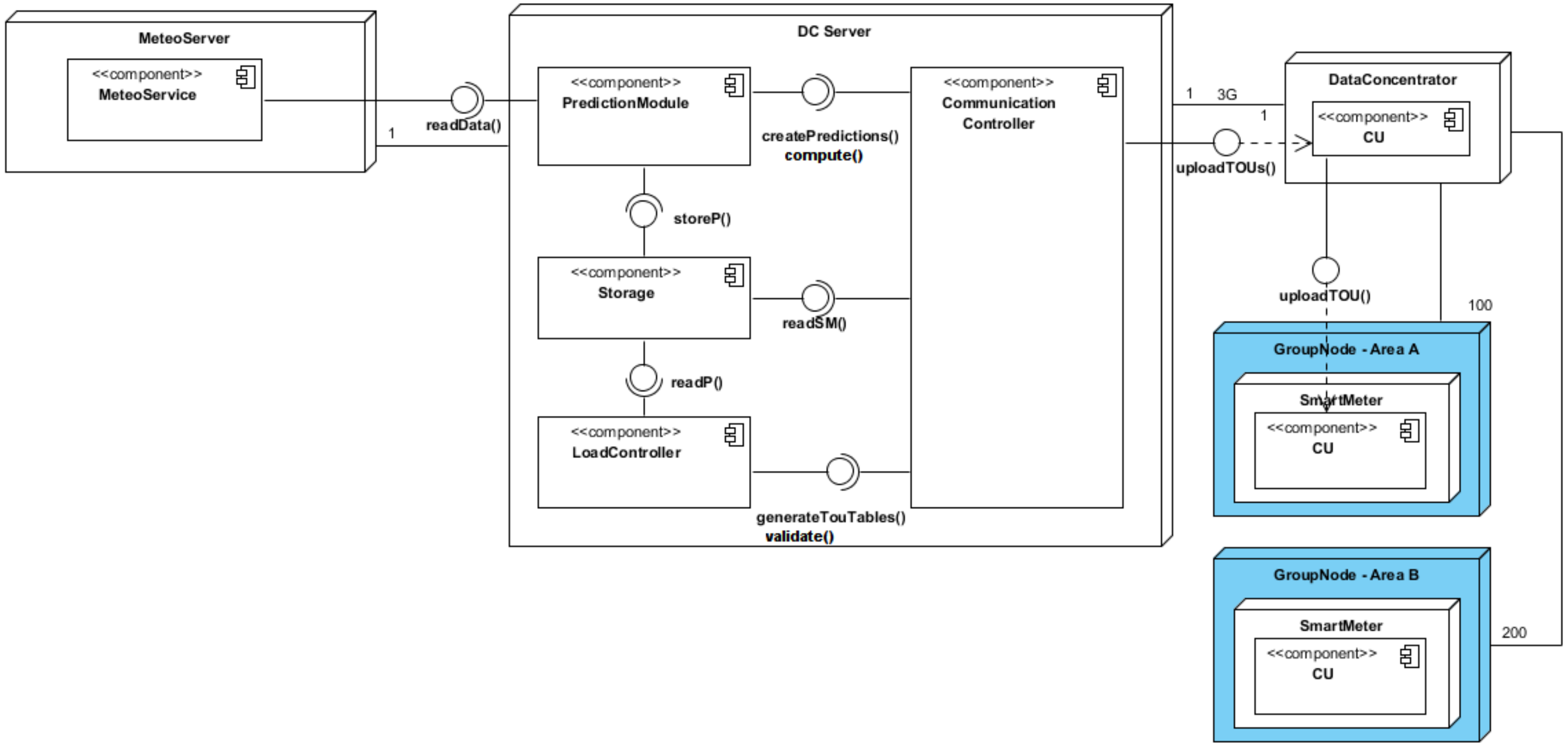


Large number of devices - SPNP



- 100 tokens for messages and 100 tokens for SM
- G_transferOk = [#transfer<=#SMup]
- Reachability Graph/CTMC
  - 1 040 502 markings
  - 4 797 703 transitions
  - ~ 10min computation

Large number of devices – Group nodes

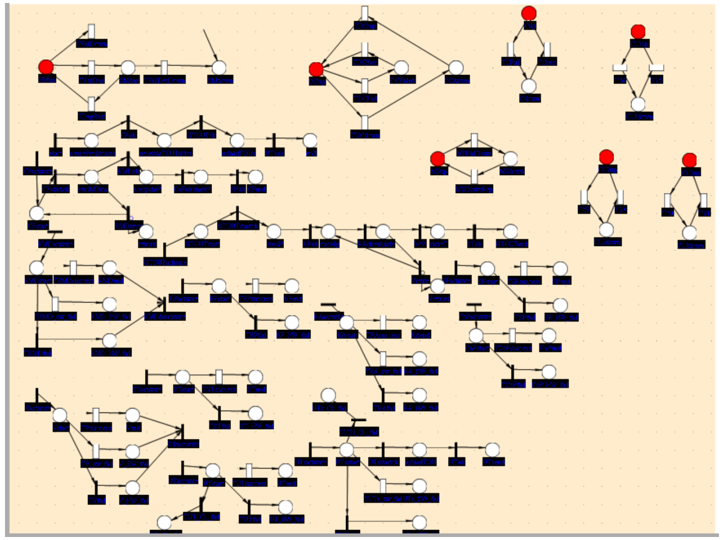


- Group nodes (GNs) represent large number of HW nodes
  - Group nodes for different locations, technologies, etc. with different parameters
- Alternatively, GNs could contain sub-nodes for different classed of devices.

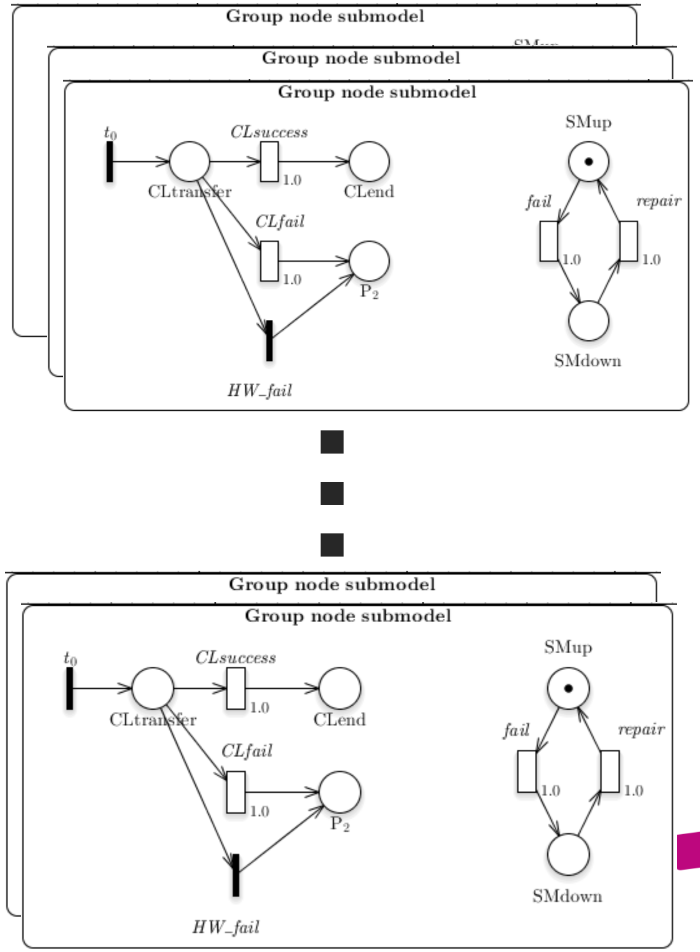
Large number of devices – Group nodes II

- GN submodel is solved first and serves as input for Service/HW model

Service/HW model



Failure/success rates, number of successes



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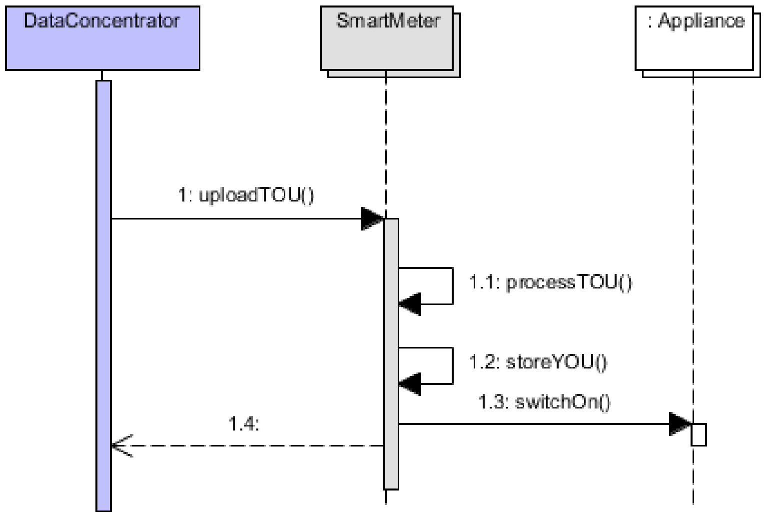
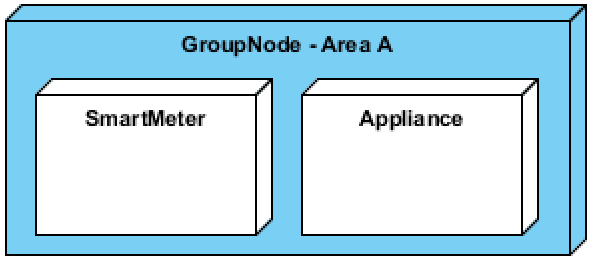
Large number of devices – Possible enhancements

- Modelling of more complex services in the group nodes
  - Each of the device in the group node can have some internal behaviour or it can communicate with other devices
  - The submodels might be fully specified service/HW models
    - The output for the main model can be computed at the point of the return message.





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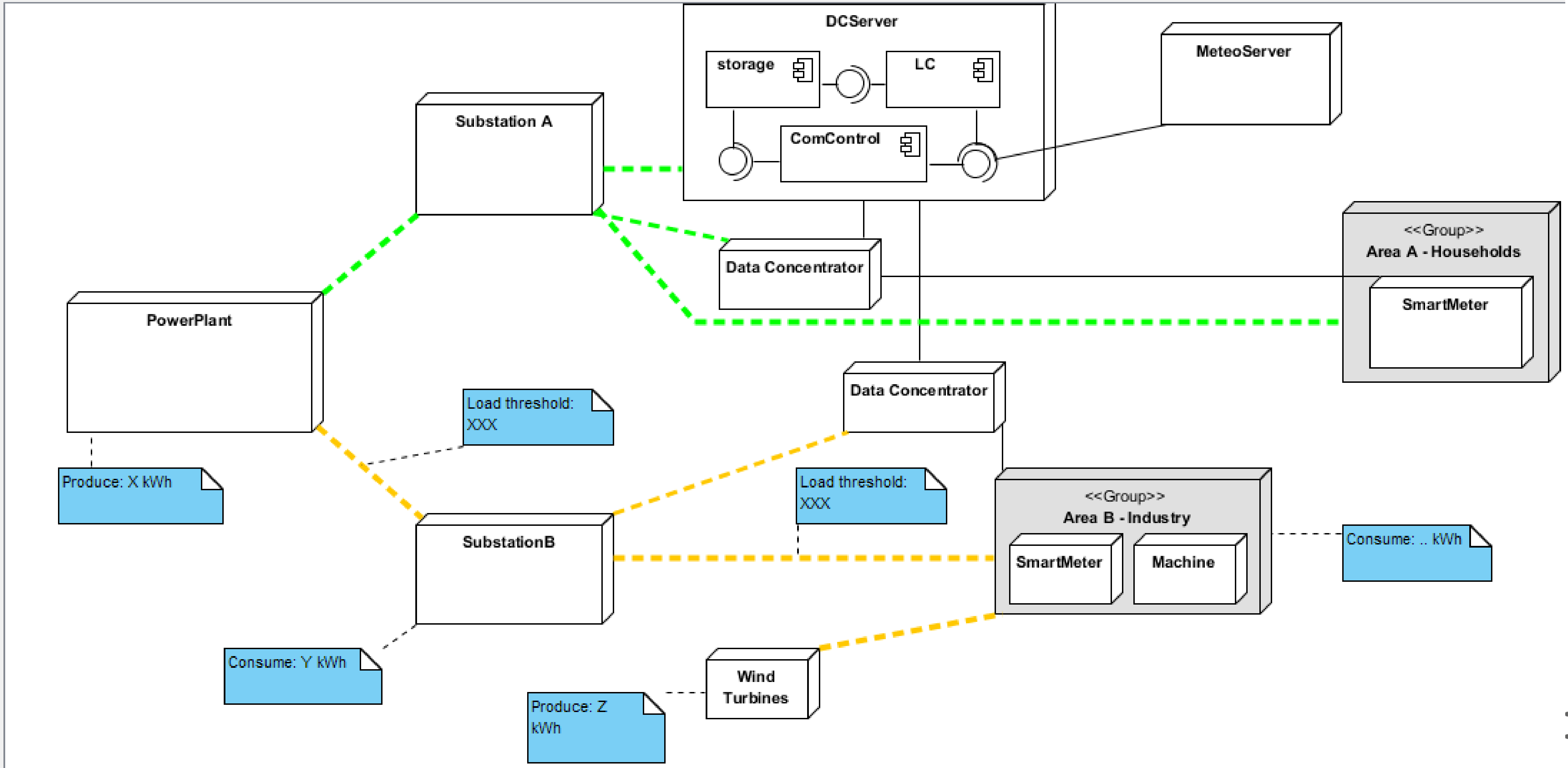
Resource management – Energy requirements



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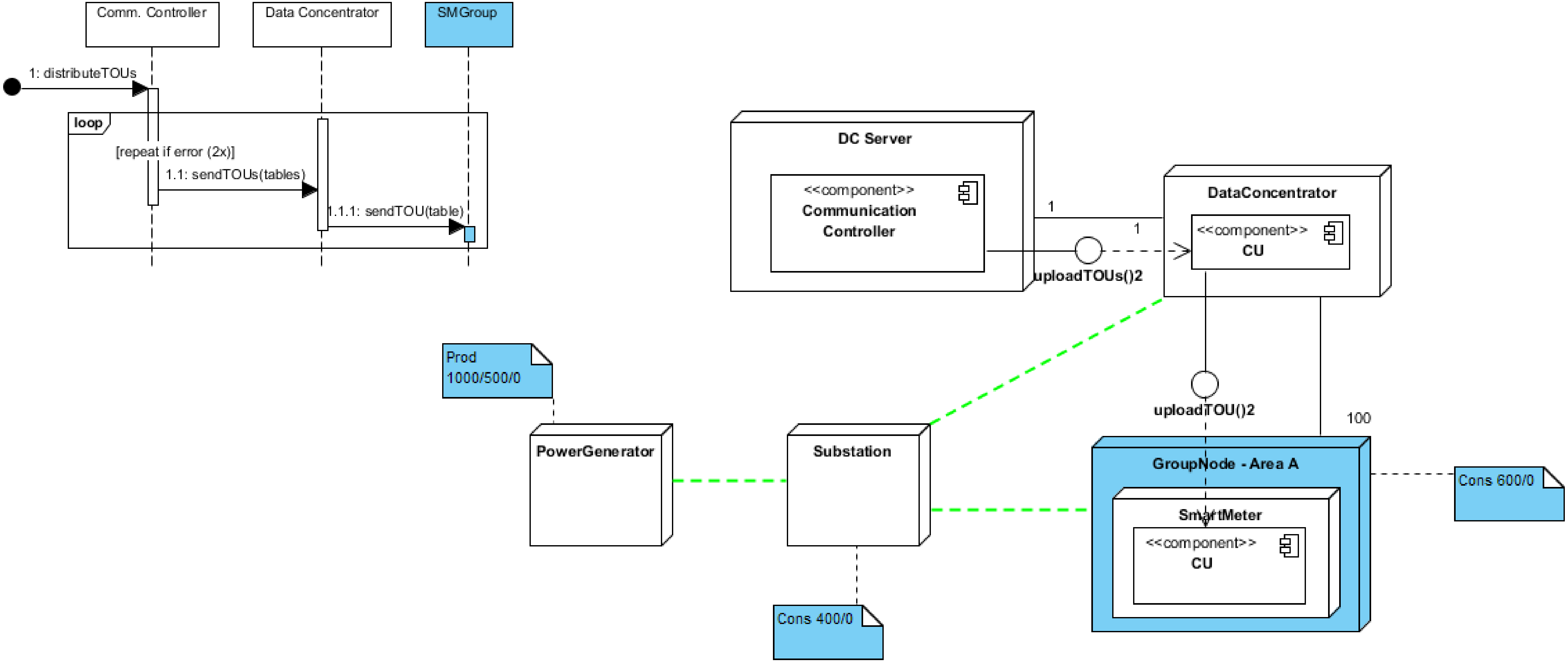
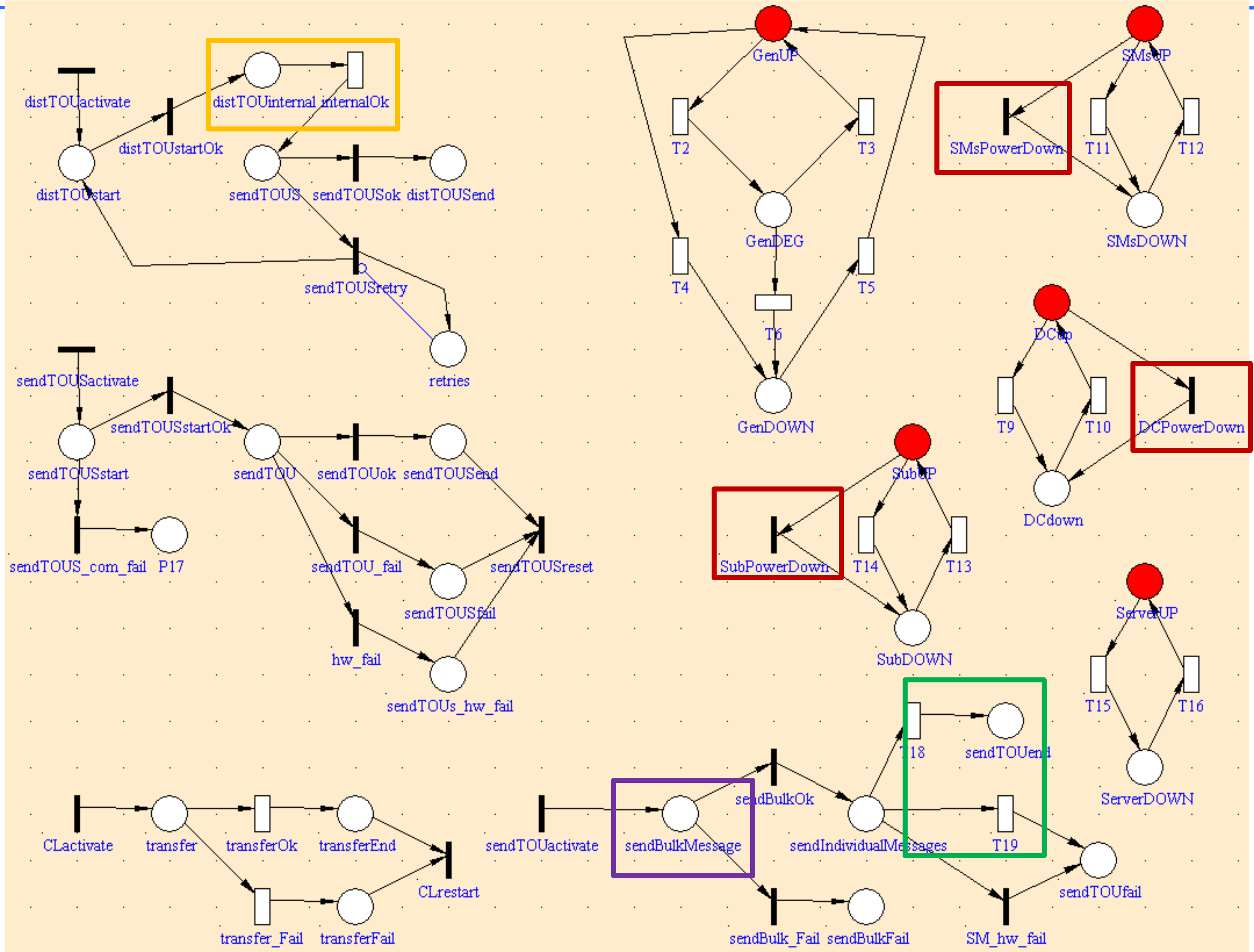
Scenario – Sending TOU tables



Scenario – Sending TOU tables



- PN
  - 30 places
  - 20 trans.
- RG
  - 174 markings
  - 752 trans.

Input Data

- Operational data
  - Operations/methods being executed
  - Duration of individual operations
  - Sources
    - Application logs
    - Event logs
- Failure data
  - Possible failure types
  - Frequency of failure occurrence
  - Sources
    - Application & event logs
    - Crash logs
    - Documentation
- Communication data
  - Message sizes, link reliability, communication duration
  - Sources
    - Communication logs
    - Network monitoring

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Related Projects

- C4E - Simulation and prediction analysis of critical infrastructures
  - Extension to other types of infrastructures
  - Adding support for other qualitative attributes – availability, performance
  - Case studies
- Hardware-Software Fault Analysis for Cyber-Physical Systems of Systems
  - General Failure, Error and Fault (FEF) classification, taxonomy and ontology
  - Catalogue of FEF
  - Preparing proposal for H2020

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Next Steps

- Validation
  - Validation of the **abstraction**
  - Validation of input **parameter assumptions**
  - Evaluation of the **largeness** and **stiffness** problems
  - Comparison of **analytical** and **simulation** results (in the SPNP tool)
  - **Cross-validation** through implementation in different simulator, e.g. GridMind
- Tool for model generation from annotated UML diagrams
- Future research
  - Extension of the model with additional measures – availability, performance, survivability, …
  - Application of the model to different domains – smart cities, software systems, automotive…
  - Optimization of the state-space, improvement of the abstraction