An Integrated Modeling Approach for Analyzing Dependability, Cost and Sustainability of IT Data Center Systems

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Agenda

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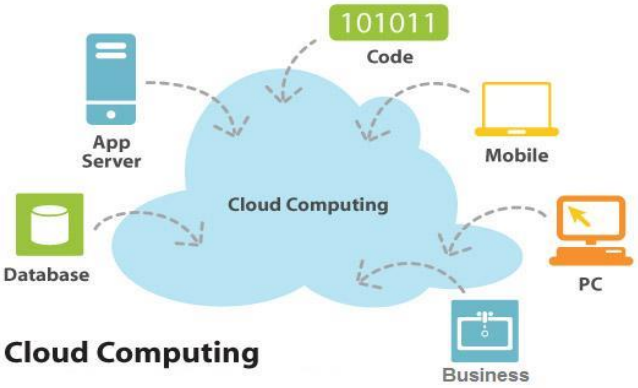
- Objective
- Preliminaries
  - Data Center Infrastructure
  - Metrics
  - Exergy
  - Stochastic Petri Nets
  - Reliability Block Diagrams
- Models
- Mercury Environment
- Case Study
- Conclusion

Introduction

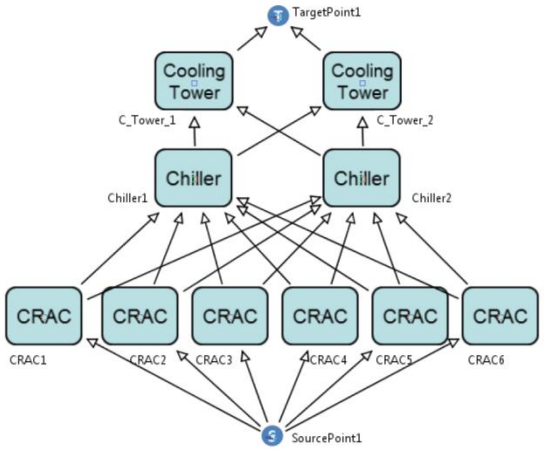
- Data centers are growing
- Fact (Considering U.S.)
  - Data centers consume about 2 % of the whole power generated .
- Concern about
  - Energy Consumption,
  - Environmental Sustainability.
- Sustainable data centers
  - Least amount of materials,
  - Least energy consumption.
- Availability
- Fault-Tolerance



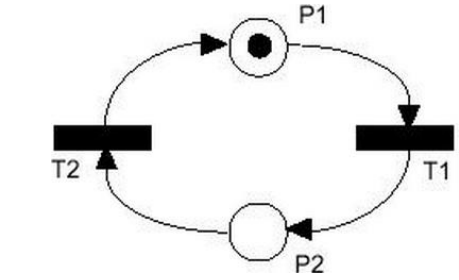
Objective

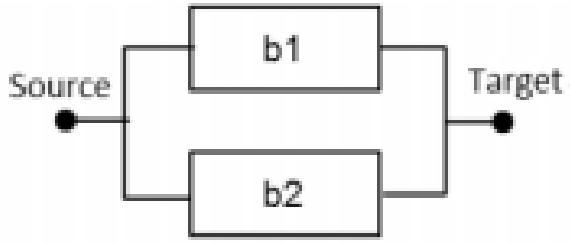
- **To provide:**
  - a set of **models** for the integrated **quantification** of **sustainability** impact, **cost** and **dependability** of IT data center infrastructures.

Energy Flow Model,

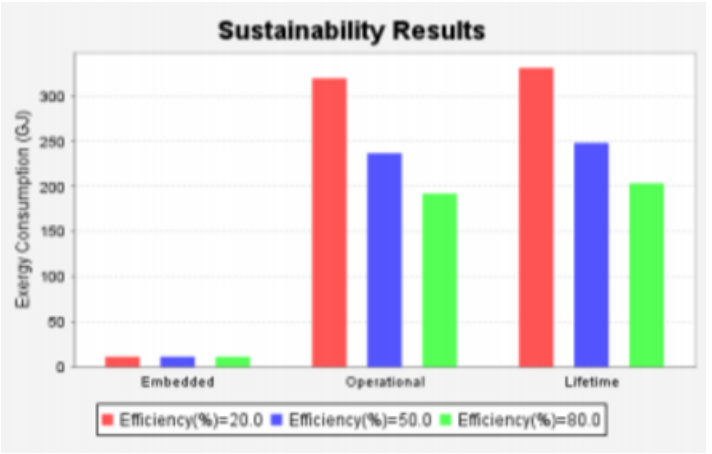


SPN and RBD



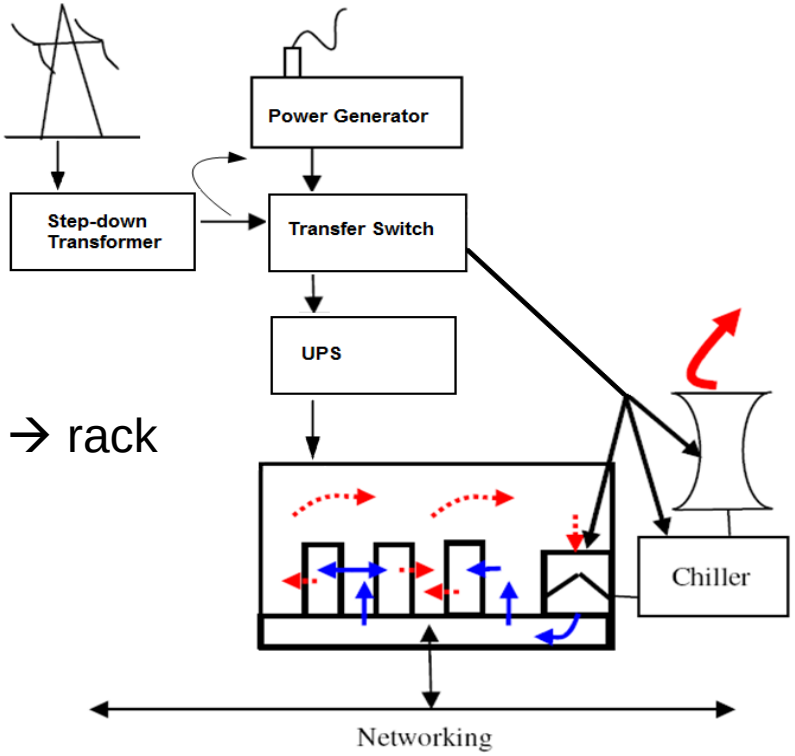


→ availability, downtime, cost sustainability impact, etc



Data Center Infrastructure

- IT infrastructure:
  - Servers,
  - Networking equipment,
  - Storage devices.
- Power infrastructure:
  - SDT → transfer switches → UPS → PDUs → rack
- Cooling infrastructure:
  - Extracts heat → prevents overheating
  - CRAC, Cooling Tower, Chiller



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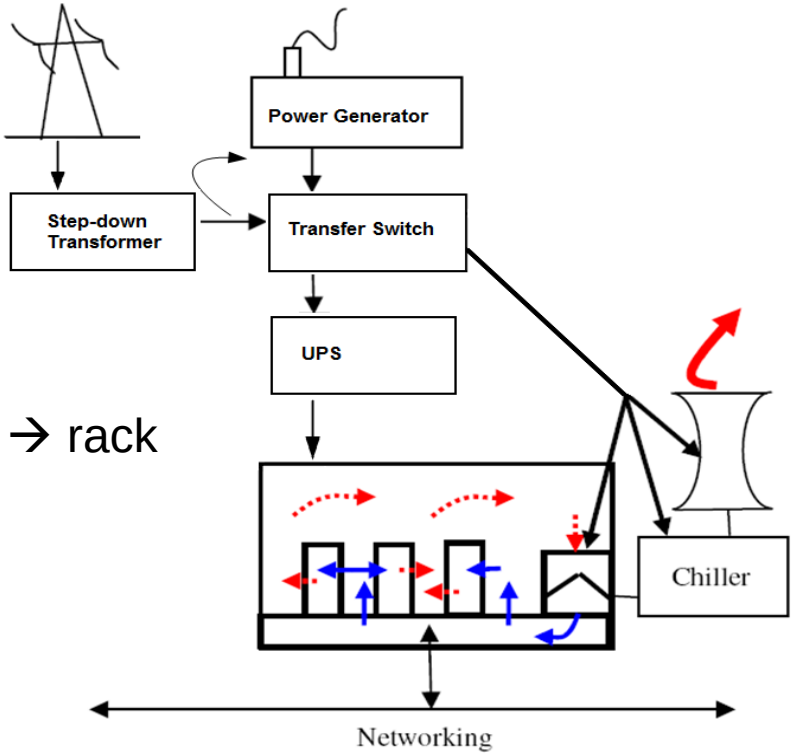


Metrics

- Dependability
  - Availability
- Sustainability Impact
  - Exergy Consumption
  - Energy Consumption
- Cost
  - Acquisition cost
  - Operational cost

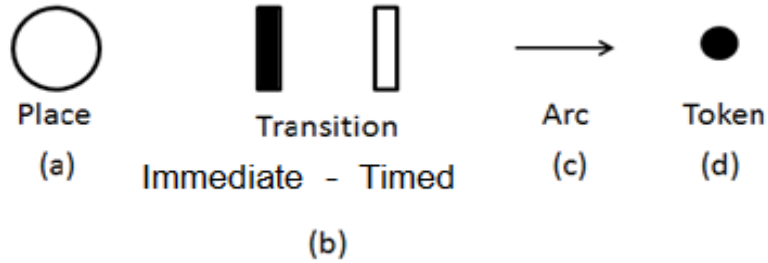
Exergy

- **Energy** can **never** be **destroyed** (FLT).
- **Exergy** can be **destroyed** (SLT).
- The **exergy** destruction or **consumption** (**irreversibility**) must be appropriately **minimized** to obtain sustainable development.

- Exergy (available energy)
  - Represents the maximal theoretical portion of the energy that could be converted into work;
  - A system which consumes the least amount of exergy is often the most sustainable;
  - **Exergy** is **useful** when **measuring** the **efficiency** of an energy conversion process

Stochastic Petri Net (SPN)

- Graphical and Mathematical modeling tool
- For modeling:
  - concurrency,
  - synchronization,
  - communication mechanisms,
  - deterministic and probabilistic delays



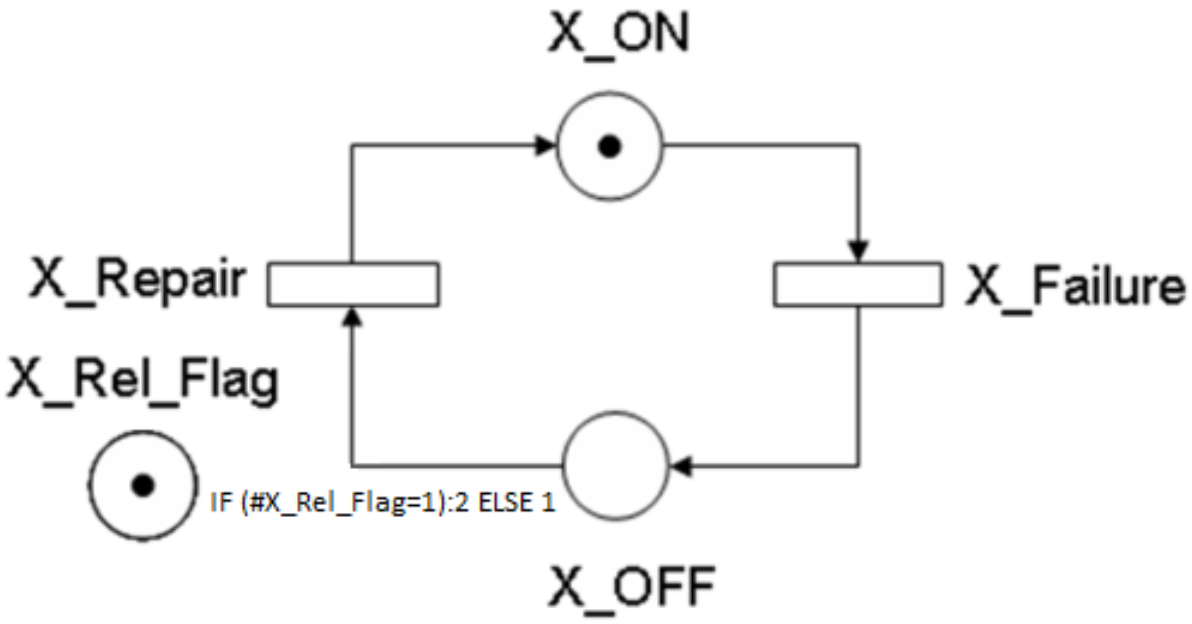
- SPNs extend PNs.

- Each transition has a firing time assigned to it:
  - timed transitions (exponentially distributed)
  - immediate transitions

Stochastic Petri Net (SPN)

- Simple Component

$$P\{\#X\_OFF > 0\}$$



Stochastic Petri Net (SPN)

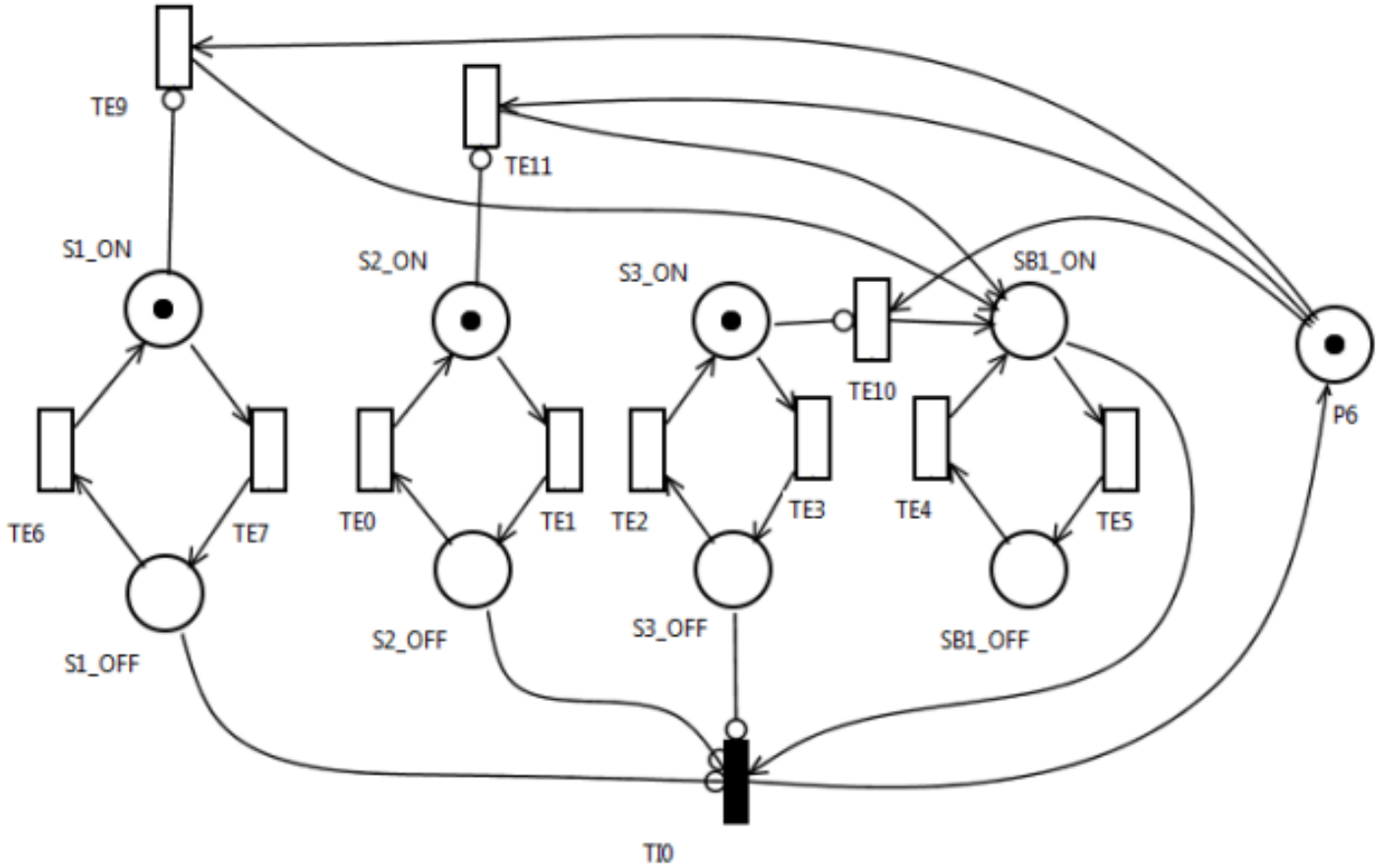
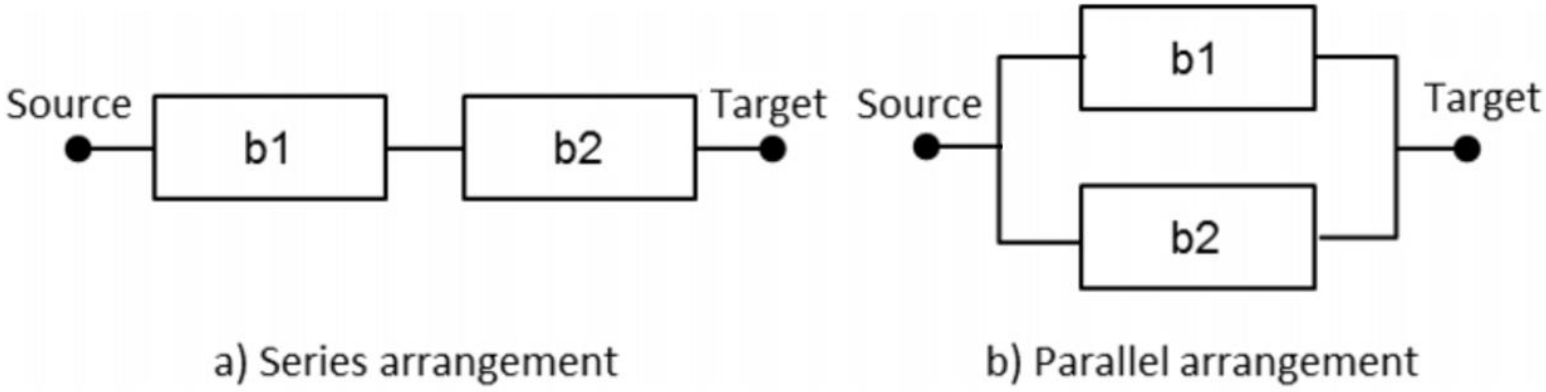


Fig. 7. SPN model considering 3+1 servers redundancy behavior.

Reliability Block Diagrams (RBD)

- A **Reliability Block Diagram** (RBD) is a non-state space model that enables analysis of **reliability** and **availability** of complex systems using block diagrams.
- In a block diagram model, components are combined into blocks in series, parallel, or *k-out-of-n*.
- The structure of RBD establishes the logical interaction among components



Reliability Block Diagrams (RBD)

- Series $$P_s = \prod_{i=1}^{n} P_i$$

- Parallel $$P_p = 1 - \prod_{i=1}^{n} (1 - P_i)$$

where P_i is the reliability - $R_i(t)$ (instantaneous availability $(A_i(t))$ or steady state availability (A_i)) of block b_i.

Energy Flow Model

- The **system** under evaluation can be **correctly arranged**, **but** they **may not** be able to **meet system demand** for electrical energy.

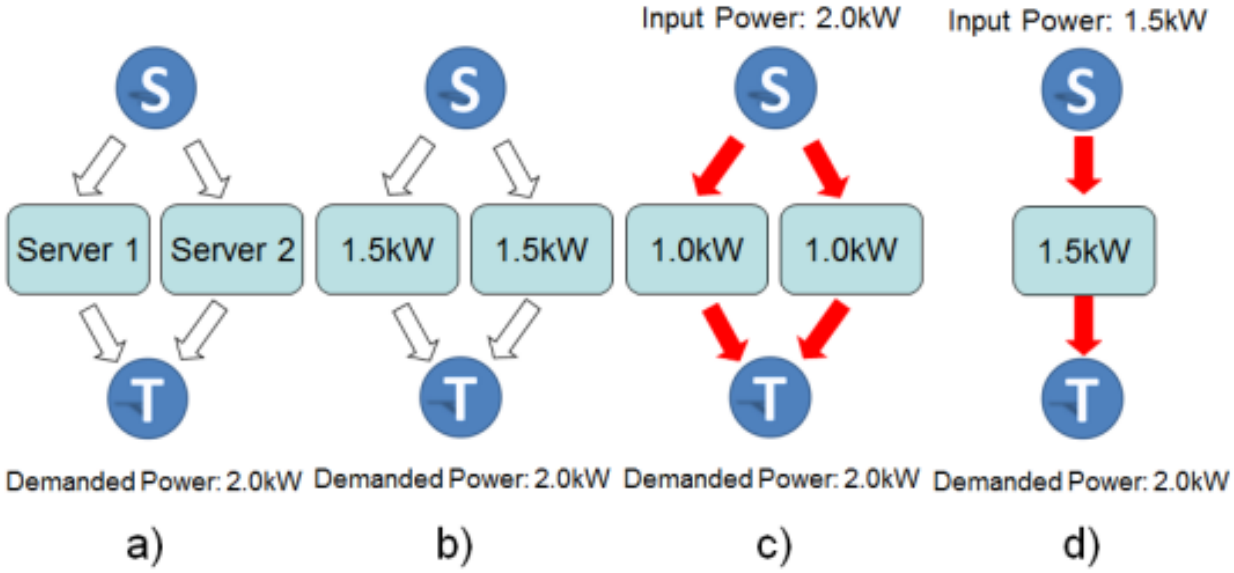
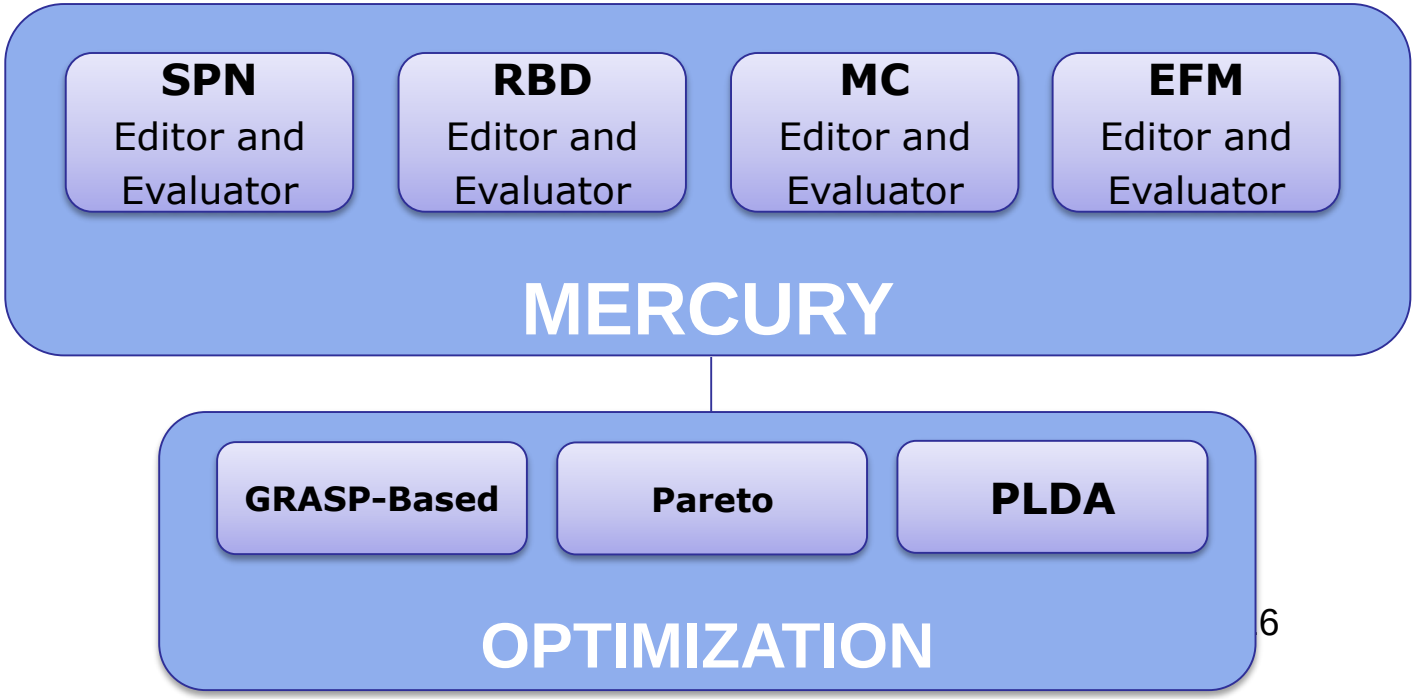


Fig. 5. a) IT System example; b) Maximum Capacity; c) Successful Energy Flow; d) Failed Energy Flow.

Mercury Environment



Case Study I

- The main **goal** of this paper is to **support** data center **designers** in relation to metrics such as **cost**, **availability** and **sustainability** taking into account **IT** infrastructures.

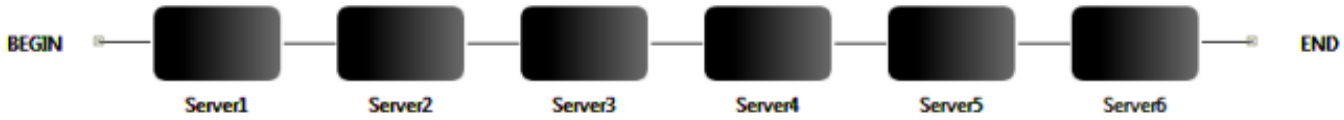
- In order to illustrate this, we have been modeling a **data center** infrastructure that supports **60 racks of servers** as well as other devices (**routers** and **switches**) to provide the necessary communication environment.

Scenarios

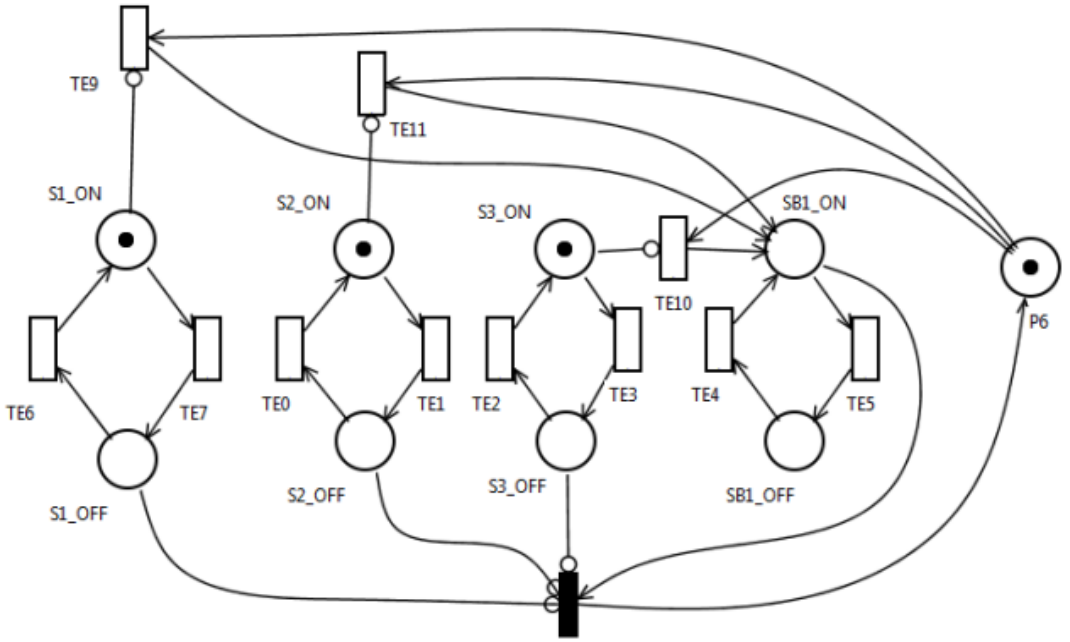
- Scenarios:
  - I: each **rack** is composed of **6 servers without redundancy**.
  - II: racks composed of **8 servers** with two subsystems of **3+1** redundancy, in which the time of 150 seconds is considered for activating a spare server.
  - III considers **10 servers** into two groups of **3+2 redundancy** also taking into account 150 seconds to activate the backup server.
  - IV: corresponds to the **second** one in **without activation time**
  - V: adopts the **third** scenario **without** assuming the activation **time**.

Dependability Models for IT RACKS

- Scenario I



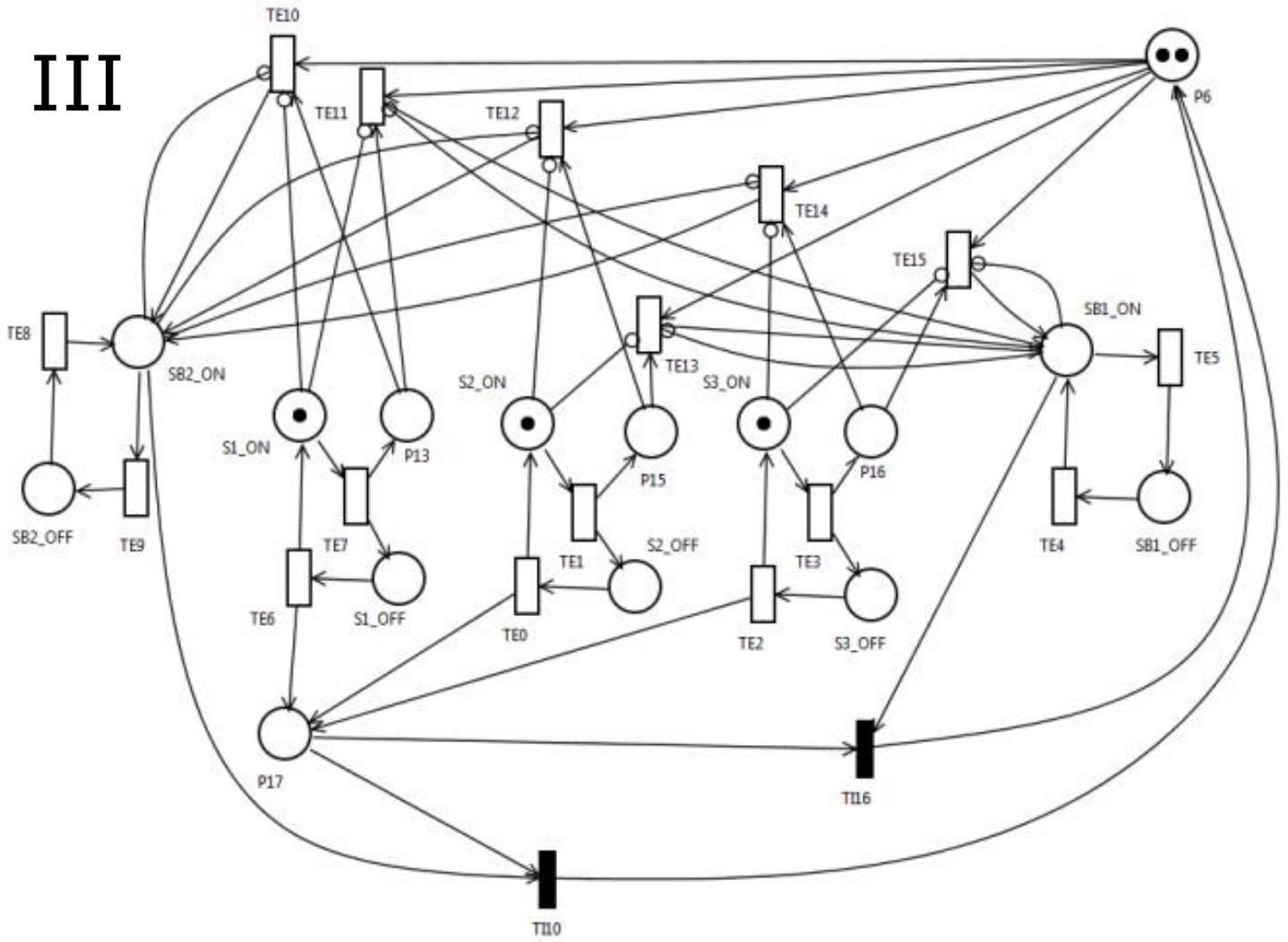
- Scenario II



$$P\{((\#S1\_ON=1)AND(\#S2\_ON=1)AND(\#S3\_ON=1))$$
$$OR((\#SB1\_ON=1)AND\ (\#S1\_ON=1)AND(\#S2\_ON=1))$$
$$OR((\#SB1\_ON=1)AND(\#S2\_ON=1)AND(\#S3\_ON=1))$$
$$OR((\#SB1\_ON=1)AND(\#S1\_ON=1)AND(\#S3\_ON=1))\}.$$

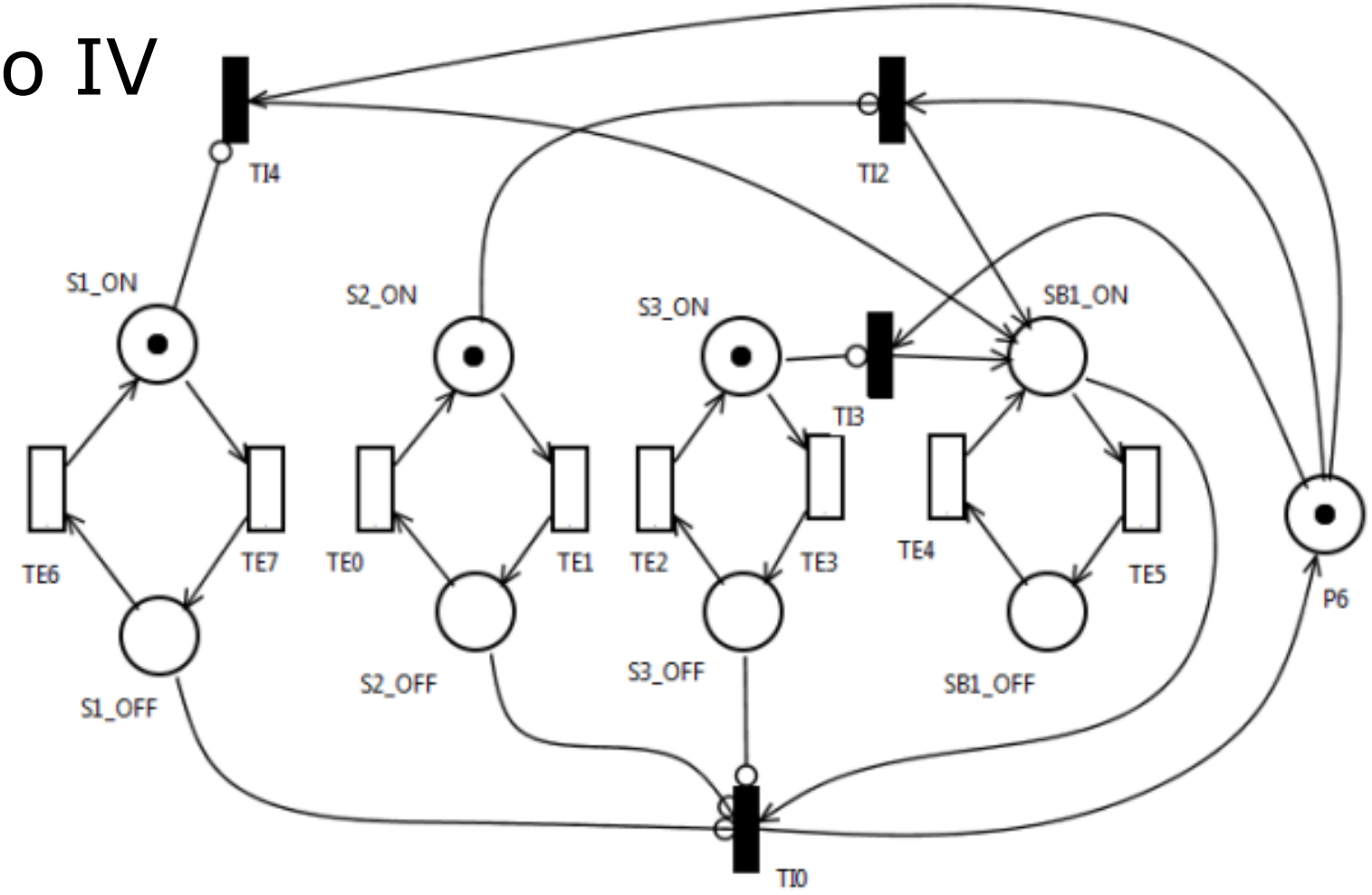
Dependability Models for IT RACKS

- Scenario III



Dependability Models for IT RACKS

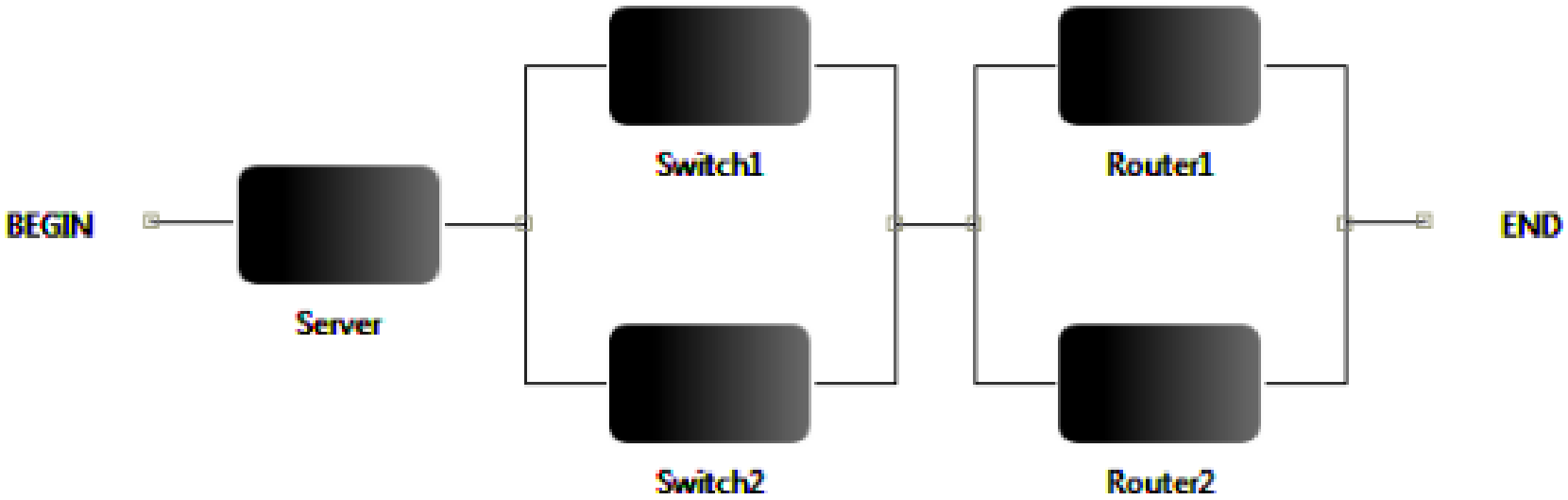
- Scenario IV



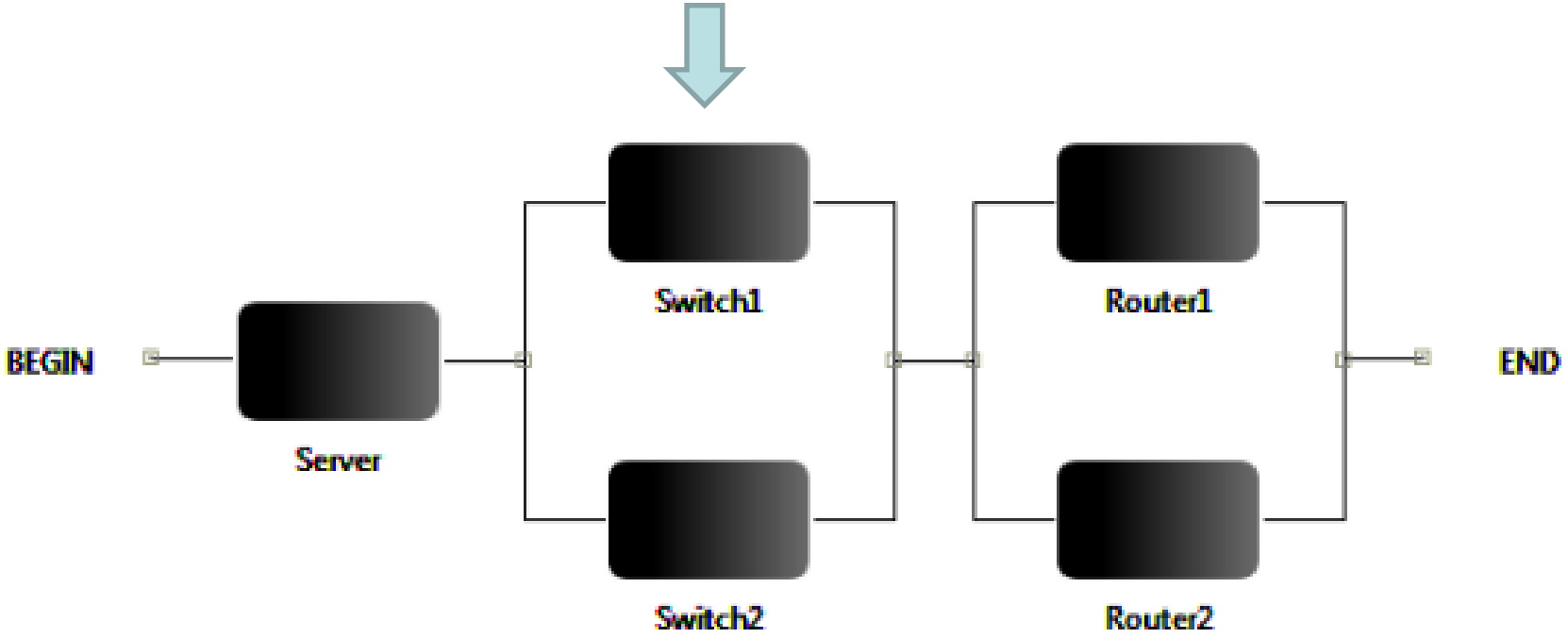
Dependability Models

- IT system
  - server racks,
  - switches and
  - routers.
- 20 switches of 48ports
  - two completely redundant paths
  - two subsystems of 10 switches each
- Two routers

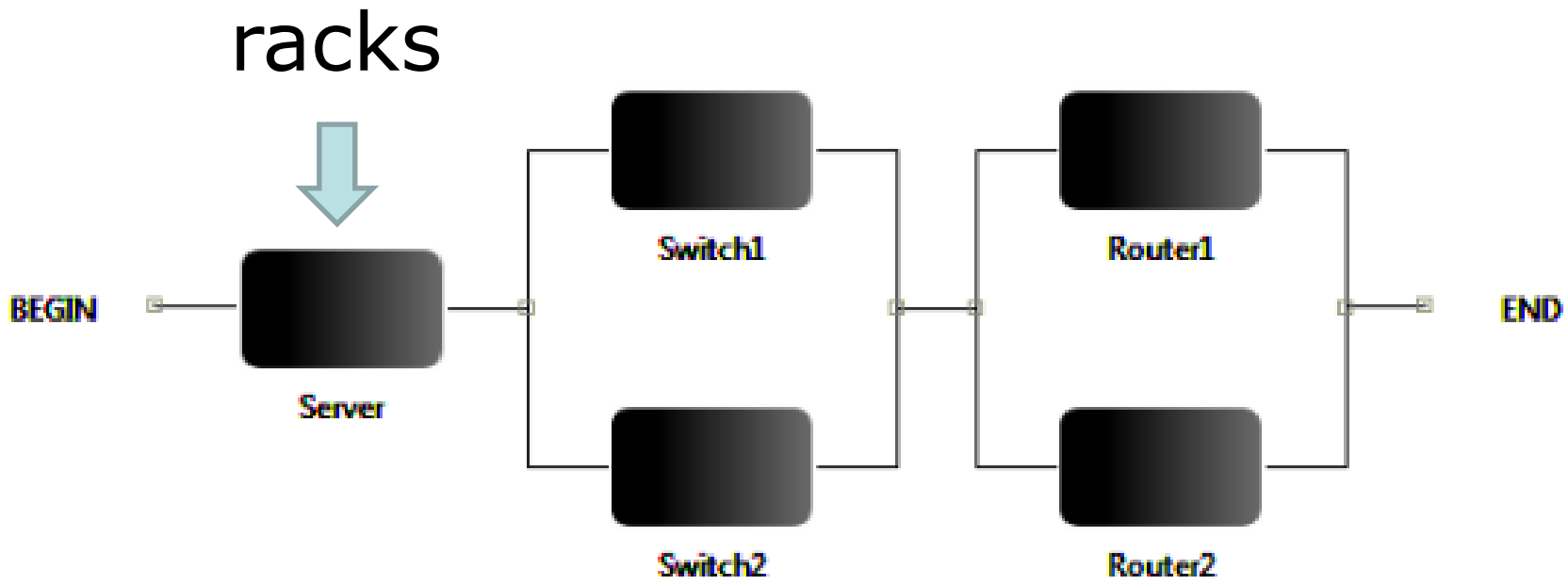
System Dependability



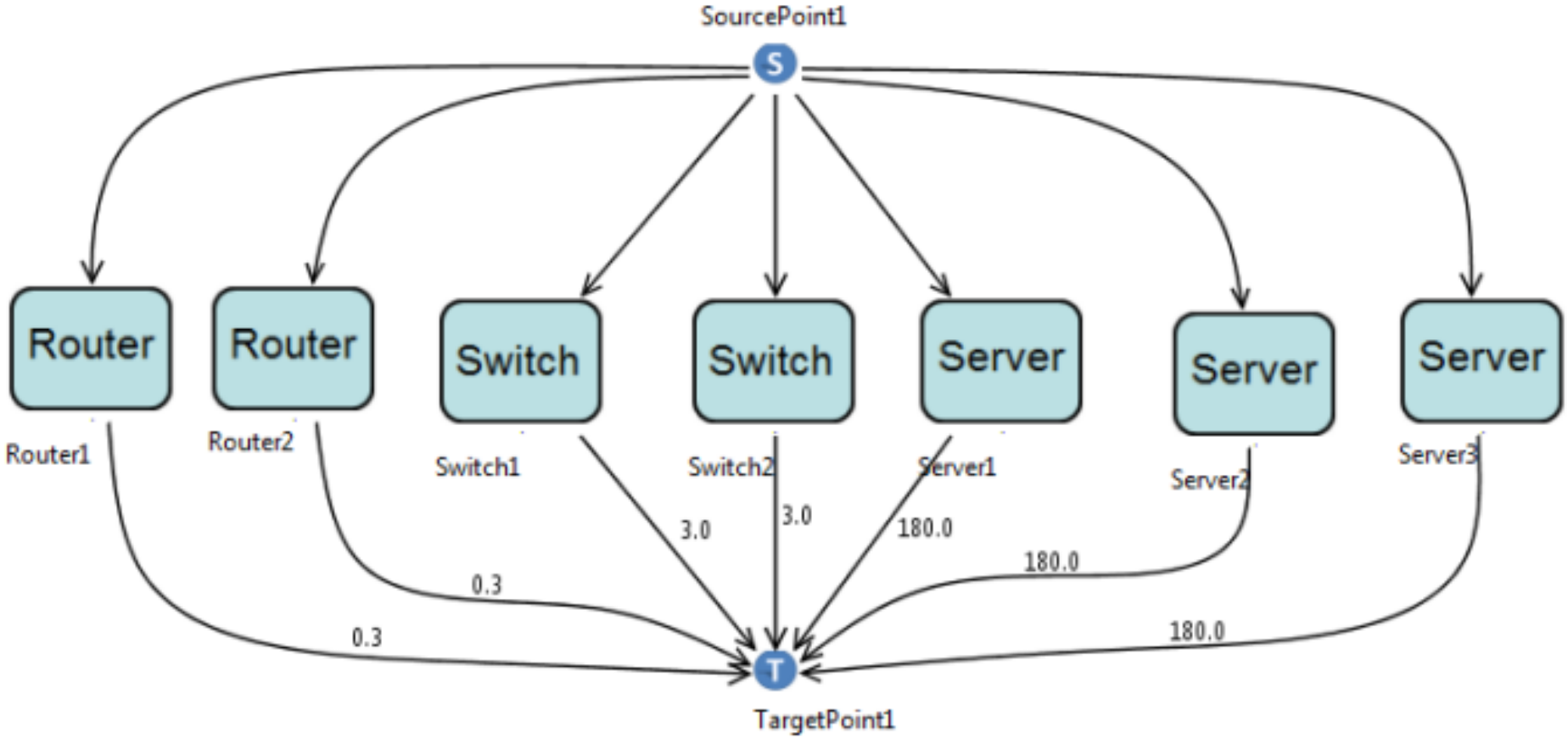
Each switch represents 10 switches



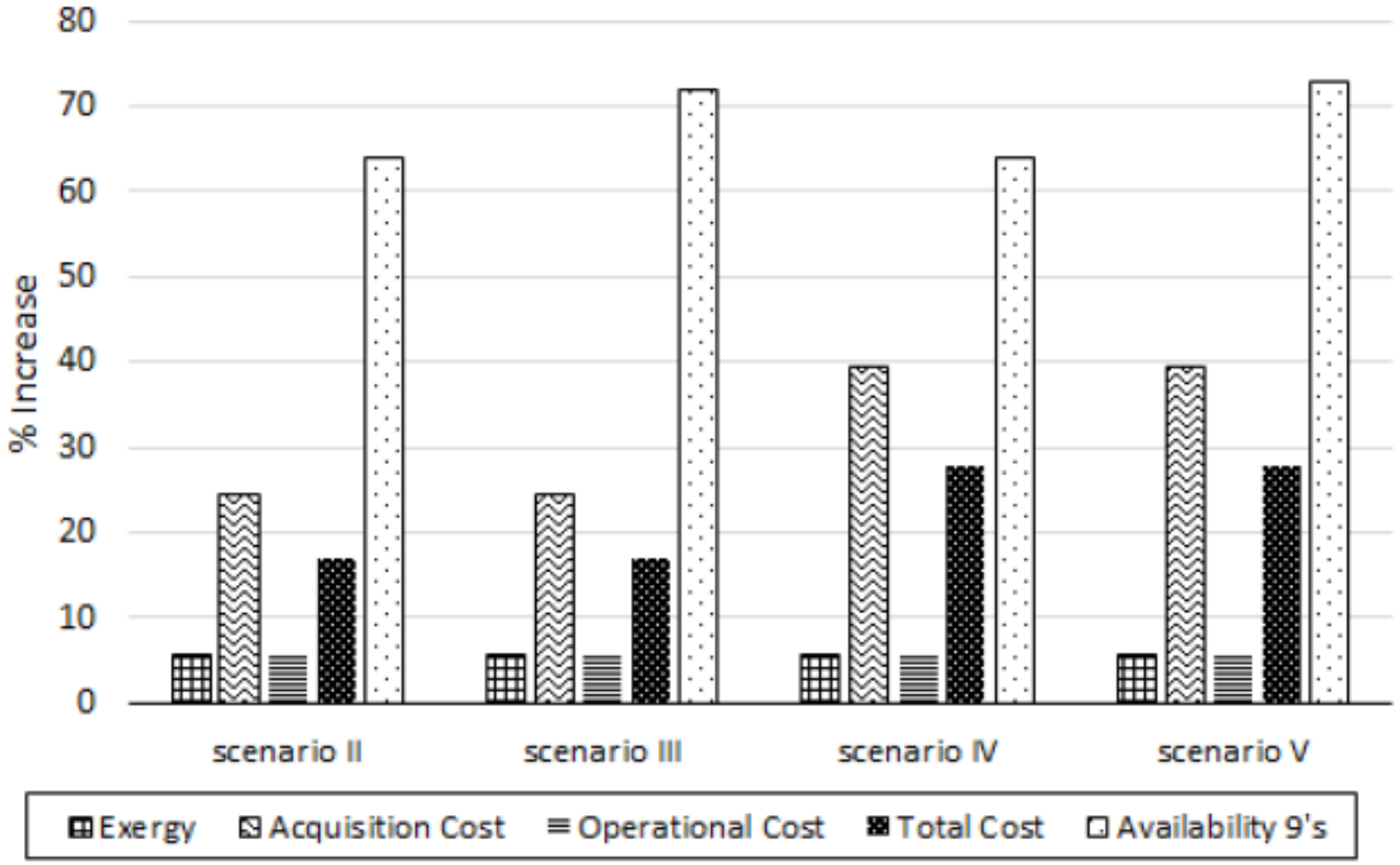
System Dependability



EFM Model


SourcePoint1
S
Router
Router
Switch
Switch
Server
Server
Server
Router1
Router2
Switch1
Switch2
Server1
Server2
Server3
3.0
3.0
180.0
180.0
0.3
0.3
180.0
T
TargetPoint1

Results


80
70
60
50
40
30
20
10
0
% Increase
scenario II
scenario III
scenario IV
scenario V
Exergy
Acquisition Cost
Operational Cost
Total Cost
Availability 9's

Final Remarks

- Data center **designers do not have** many **mechanisms** to support the **integrated** sustainability, cost and dependability **evaluation** of **IT** data center infrastructures.

- This work aims at **reducing** this **gap** by proposing **models** (supported by the developed environment Mercury)

- As a **future work**, we intend to **extend** the **EFM** to support the verication of other IT metrics (e.g., maximum number of requests or packages).

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