Critical Infrastructure Simulator by Interdependent Agent

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https://dl.dropboxusercontent.com/u/3945029/Cisia.pdf

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Purpose of this lesson

The objective of this lesson is to describe CISIA simulator and its element. At the end the MICIE reference scenario is described.

Reading Materials

The State of the Art in Critical Infrastructure Protection: a Framework for Convergence, by Ebrahim Bagheri and Ali A. Ghorbani, 2007

An agent based simulator for critical interdependent infrastructures., by Panzieri, S., Setola, R., Ulivi, G., 2004.

An approach to model complex interdependent infrastructures., by Panzieri, S., Setola, R., Ulivi, G., 2005.

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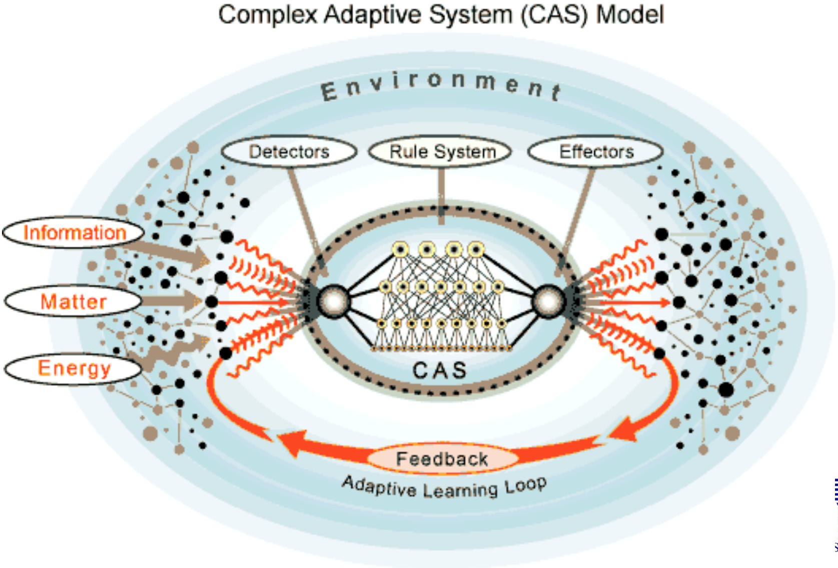
Complex Adaptive Systems



Complex Adaptive Systems

The whole model is obtained considering a population of interacting agents, where an *agent* is an entity with a location, capabilities and memory.
The agent location defines where it is in a physical space (*geographic* region or abstract space). What the agent can perform is defined by its capabilities. An agent can modify its internal data representation (*perception* capability), it can modify its environment (*behaviours* capability), it can adapt itself to environment's changes (*intelligent reaction* capability), it can share knowledge, information and common strategies with other entities (*cooperation* capability), and it can execute actions without external intervention (*autonomy* capability). Finally, the experience history (for example, overuse or aging) and data defining the agent state represent agent's memory.
Interaction among them produces the "emergence" of behaviours that are not predictable by the knowledge of any single agent.

Agent-Based Modelling

ABM is obtained interconnecting agents: i.e., independent systems that autonomously elaborate information and resources in order to define their outputs; the latter became inputs for other agents, and so on.
This approach is particularly useful for situations, as is the case of infrastructure interdependencies, with sparse or non-existent macroscale information; ABM is able to use the rich sources of micro-level data to develop interaction forecasts.
One disadvantage of these simulation models is that the complexity of the computer programs tends to obscure the underlying assumptions and the inevitable subjective inputs. An other disadvantage is the difficulty to acquire detailed information about each single infrastructure. This task appears, by its own, a difficult challenge, because this kind of information is considered very sensible by infrastructure stakeholders due to the relevance for their business. The consequence of a disclosure of these kind of information could have a bad impact on the markets.

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Critical Infrastructure Simulation by Interdependent Agents I

CISIA main aims are:

- To evaluate the short-term effects of one or more faults;
- To help analysts in what-if analysis;
- To single out the critical elements (i.e., those whose faults produce maximum impact).

CISIA models the behavior of an infrastructure (or a set of interacting infrastructures) through a set of non-linear *interdependent agents*. Each of the agents represents a macro component of the modeled system.

Critical Infrastructure Simulation by Interdependent Agents II

This description consists of only the specification of the agents' *operative level* (agents stamina), *requirements* (agents' needs), and *faults*. To model the interaction of the agents (provide mutual requirements or disseminate failure), three types of matrices namely Operative Level Incidence Matrix, Requirement Incidence Matrix, and Fault Incidence Matrices are devised.

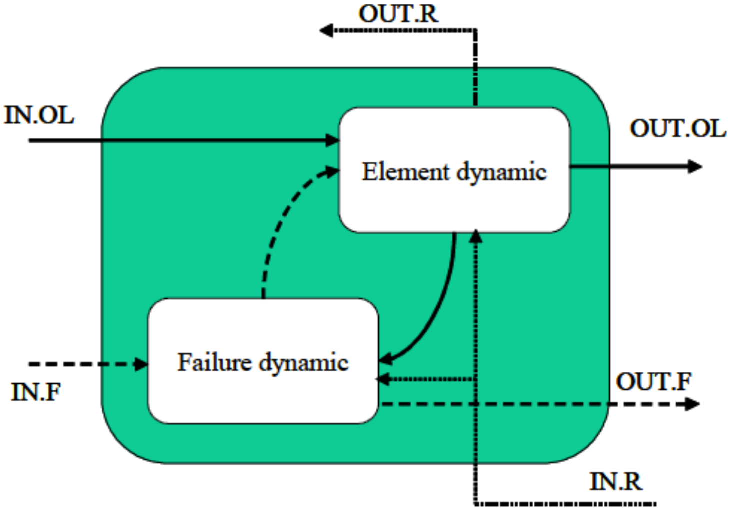
Fault incidence matrices are further refined to allow the analysis of different types of failure propagation (geographical, physical, and cyber).

Agent Representation I

In particular the agents in the simulator interact by three quantities:

- **Operative Level (OP):** the capability of the system to perform its required job. It is a measure of the potential production/service, e.g., for an energy production plant OL=100% does not means that it is providing the maximum power, but that it could, if required.
- **Requirements (R):** what the system needs to reach OL=100
- **Fault (F):** it is a structured variable composed by two components: F.value is a boolean value that, when true, forces OL zero and cannot be reverted to false, while *F.type* is a list of strings representing the different types of failures which affected the agent.

Agent Representation II



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Agent Inputs

Indeed agents are connected together when they exhibit some sort of dependence. In particular, each agent has three inputs:

1. **Induced faults (IN.F):** faults propagated to it from its neighbourhoods, described in terms of type and magnitude;
2. **Requirements (IN.R):** amount of resources requested by other agents;
3. **Operative Level (IN.OL)**): the operative level of those objects whose resources are used in it,

Agent Outputs

Each agent has also three outputs:

1. **Propagated faults (OUT:F):** faults propagated from the object to its neighbourhoods;
2. **Output Requirements (OUT:R):** amount of resources requested to other objects;;
3. **Output Operative Level (OUT:OL):** the OL of the object itself.

Internal Behaviour

One is associated to the service that the agent provides (Element Dynamic): input requirements (IN:R) coming from subsequent agents, merged with the resources available from foregoing ones (IN:OL) and the current operative level (OL), define both the output operative level (OUT:OL) and the level of resources it needs (OUT:R).

Moreover, OL depends on the level of failure of the object (OL is set to zero when F is 100%). The second dynamic (Failure dynamic) is a mix of propagation (from IN:F to OUT:F) and an internally generate condition related to agent's memory.

Dependencies Representation I

An Operative Level Incidence Matrix (m_{OL}); where the i-th row represents the set of nodes that need the output of the i-th node to perform their activities;

A Requirement Incidence Matrix (m_R); where the i-th row represents the set of nodes providing the needed resources to i-th agent. Note that even thought generally $m_{OL} = m_R^T$ we did not exploit this feature in order to guarantee a more general formulation;

Three Fault Incidence Matrices (FIMs); where the presence of a 1 in the ij-th position means that a fault may be propagated from the i-th node to the j-th one.

Dependencies Representation II

Physical FIM (m_{PF}) that describes faults propagation via the physical linkages (i.e., those related to exchange of physical quantities) between the input and the output of two agents. This kind of fault may be generated or may afflict any kind of agent.

Geographical FIM (m_{GF}) emphasizes that faults may propagate among nodes that are in close spatial proximity. Events such as an explosion or fire could create correlated disturbances to all the systems localised in the spatial neighbour. The matrix m_{GF} exhibit a pattern of 1s characterized by isolated clusters. Inside each cluster, generally, we have a fully connected structure.

Dependencies Representation III

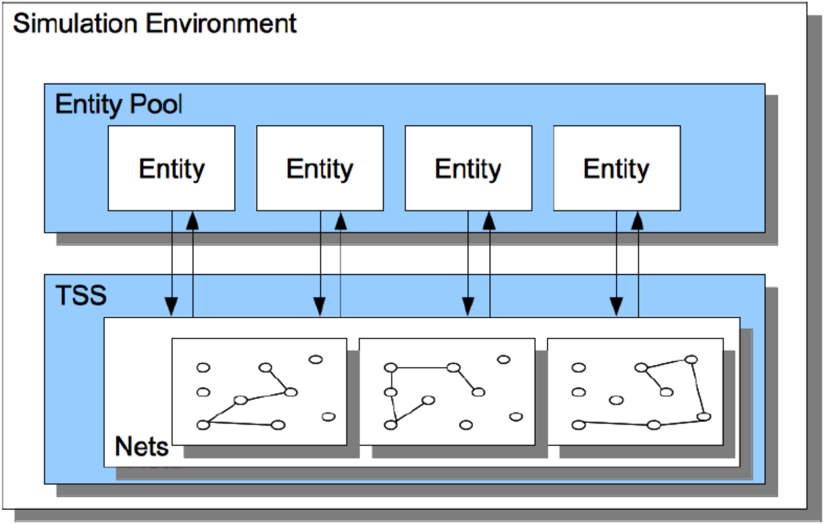
Cyber FIM (m_{CF}), this matrix describes the propagation of faults associated with the cyberspace (e.g., virus, worm, etc.). Only a subset of the agents may be affected by this class of fault, i.e., computers and apparatus directly connected to the cyberspace. Obviously, any physical failure is propagated, instead, via m_{PF} or m_{GF}. Cyber-dependency defines, at first approximation, a unicum giant cluster fully connected. This characteristic emphasizes that the cyber-dependency is a global properties, i.e., a system that uses the cyberspace is directly connected with any other system that uses the virtual space.

Simulation Steps I

Each simulation step is driven by the clock, a routine that synchronizes the computation steps of the entities with the message exchanging phase; at each step entities generate their resources and failures and such quantities are routed to other elements according to the multi-scale, multi-graph topology of the framework.

Moreover each timed cycle begins with a set of instantaneous cycles, in order to depict real-time dependencies; in fact it is not possible that an element within a power grid has to wait some cycles to receive power, such a resource has to be instantly forwarded (and the lack of such a resource has to be instantly noticed). Therefore at the beginning of every timed cycle many instant cycles are performed, until the overall system reaches a steady state.

Simulation Environment



Transmission Sub System

The TSS is devoted to manage the communication between the entities. The TSS stores the matrices which describe the different types of adjacency between the entities, as exposed above. Entities communicate via message exchanging, where each message contains data about the type and the denormalized quantity of carried resource (or fault), the normalizing factor, unit of measurement and the sender port identification (ID). When the TSS receives the signal from the simulation clock, it collects the outgoing messages from all the entities and delivers each message to the neighbours of the sender entity, according to the adjacencies described in the matrix associated with the type of the carried quantity. If a link between two adjacent entities is characterized by attenuation or delay factors, TSS provides to delay the delivery of the messages routed over that link and to suitable scale the carried quantities.

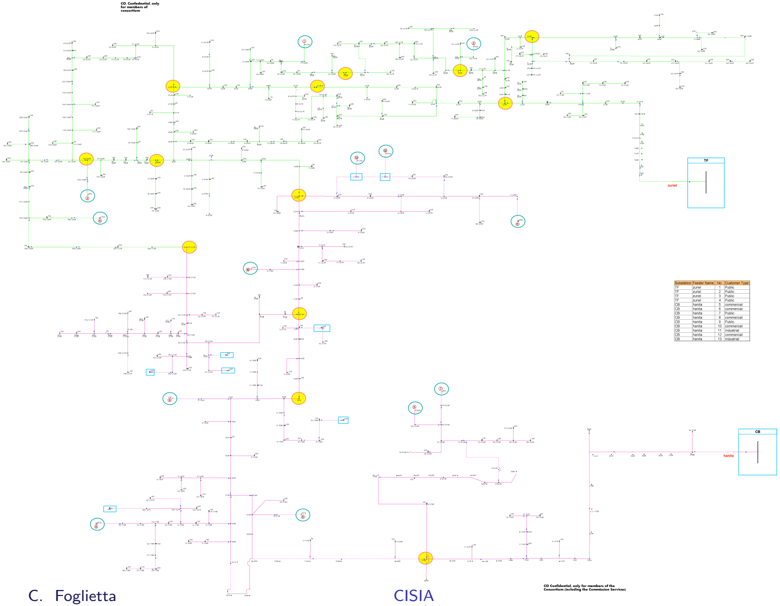
Entity Pool

The Entity Pool (EP) synchronizes the execution steps of the entities and to manage their persistence. EP stores the entities inside a multi indexed vector, keeping also the map between the communication ports and the correspondent entities. When it receives a signal from the simulation clock it keeps the execution control, and spanning the vector which contains the entities, launches the atomistic simulation step on each entity. Once all the entities have run their simulation steps, gives back the control to the clock. After this step the EP waits for the execution of the communication phase, exploited by the TSS. During this phase it works as a mapping interface between the calls of the TSS and the communication routines of the entities.

Triangular Fuzzy Numbers

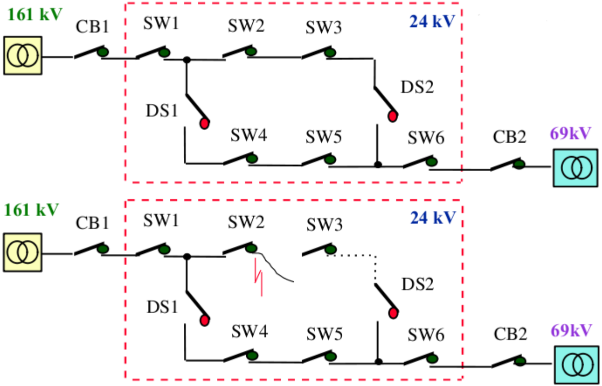
Moreover, the interdependency is modelled by means of multiple adjacency matrices, resulting in a multi-graph. Finally, each quantity is modelled by means of Triangular Fuzzy Numbers, allowing to encode vague information and providing an estimation of the certainty of the simulation/prediction.

Power Grid



Substation	Feeder Name	No.	Customer Type
TF	zuriel	1	Public
TF	zuriel	2	Public
TF	zuriel	3	Public
TF	zuriel	4	Public
CB	hanita	5	commercial
CB	hanita	6	commercial
CB	hanita	7	Public
CB	hanita	8	commercial
CB	hanita	9	Public
CB	hanita	10	commercial
CB	hanita	11	Industrial
CB	hanita	12	commercial
CB	hanita	13	Industrial

Fault Isolation and System Reconfiguration I



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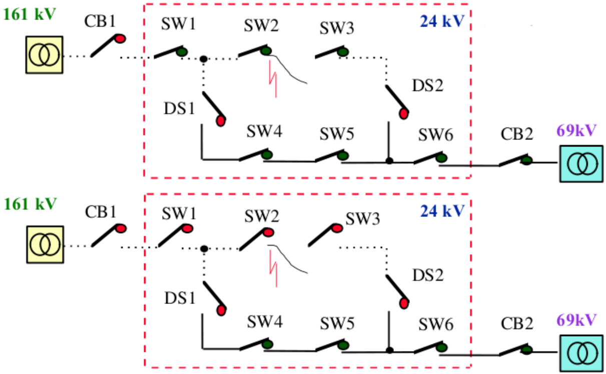
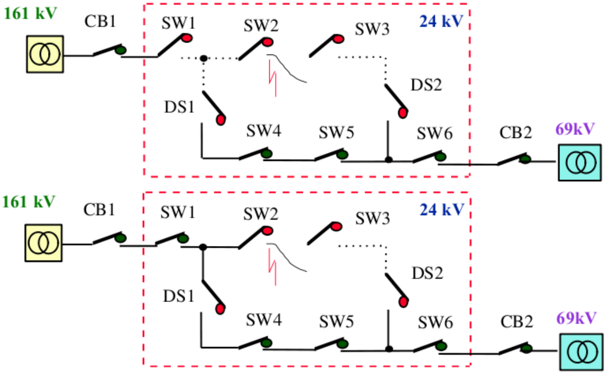
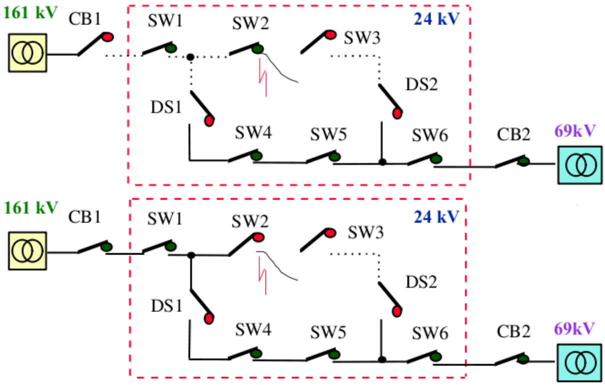
Fault Isolation and System Reconfiguration II



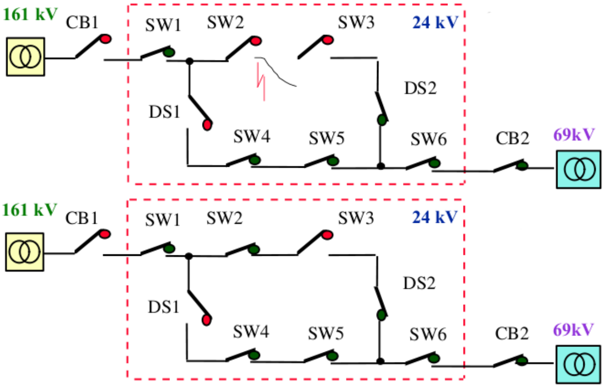
Fault Isolation and System Reconfiguration III



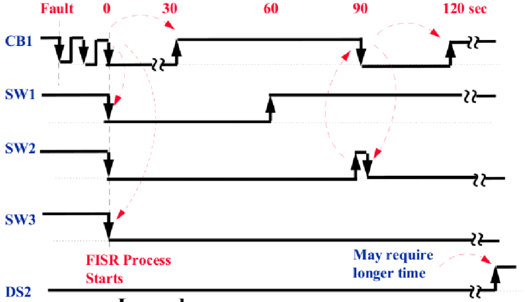
Fault Isolation and System Reconfiguration IV



Fault Isolation and System Reconfiguration V



Fault Isolation and System Reconfiguration VI



Legend:

CB1- MV Circuit Breaker/Recloser at the 161/24 kV substation

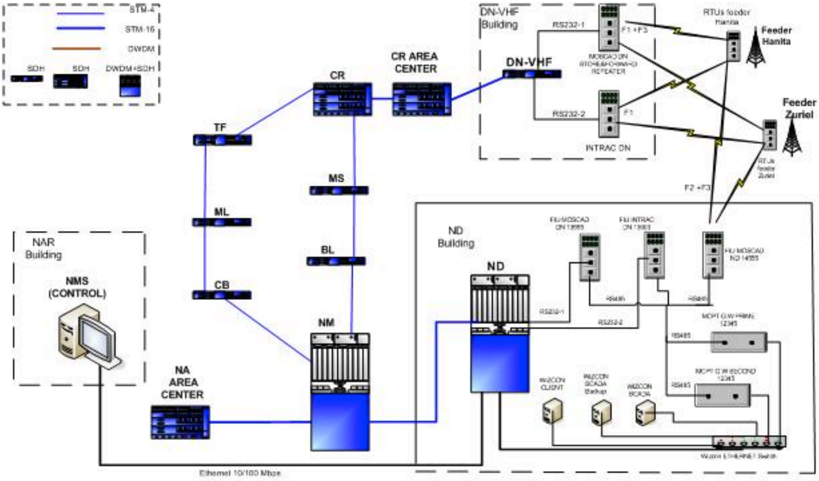
SW1 - Switch next to CB1

SW2 - Switch “next” to the fault, (closed after the repair).

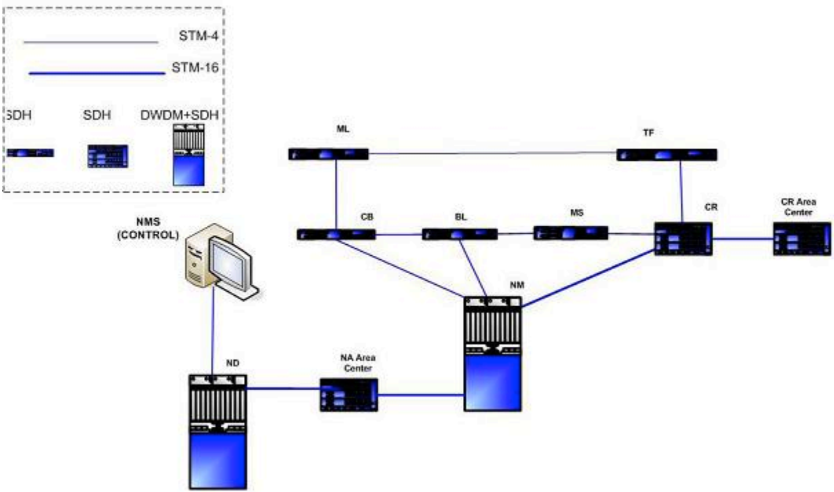
SW3 - Switch next to the fault, (closed after the repair)

DS2 - MV Disconnector which connects the two MV segments, powered from the 161/24 kV and

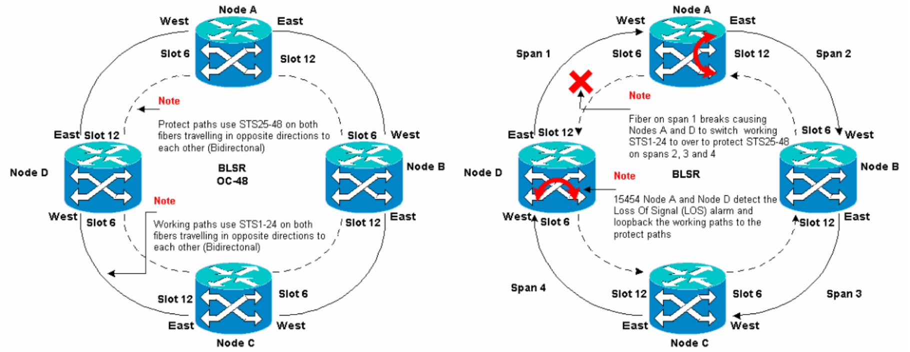
SCADA Network



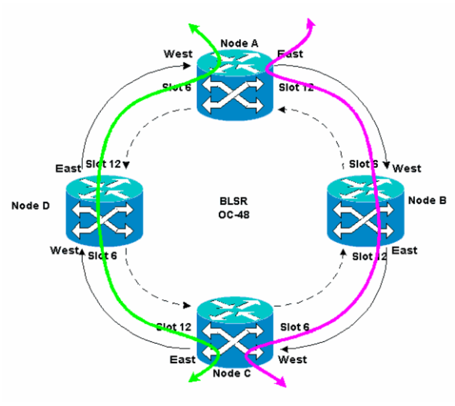
Telecommunication Network

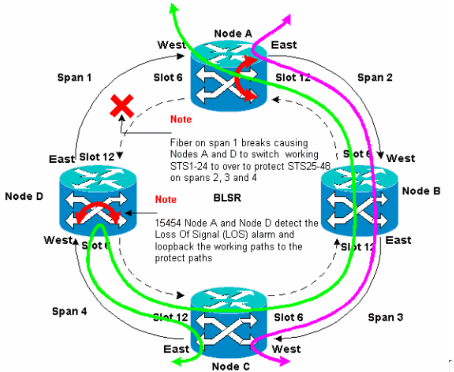


Telecommunication Reconfiguration Procedure I

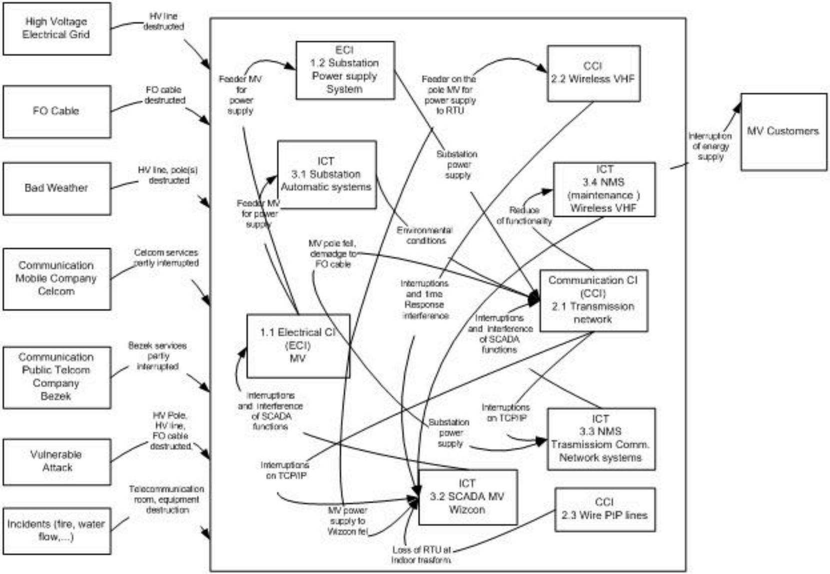


Telecommunication Reconfiguration Procedure II





Scenarios


High Voltage Electrical Grid
HV line destructed
FO Cable
FO cable destructed
Bad Weather
HV line, pole(s) destructed
Communication Mobile Company Celcom
Celcom services partly interrupted
Communication Public Telcom Company Bezek
Bezek services partly interrupted
Vulnerable Attack
HV Pole, HV line, FO cable destructed
Incidents (fire, water flow,...)
Telecommunication room, equipment destruction
ECI 1.2 Substation Power supply System
Feeder MV for power supply
Feeder on the pole MV for power supply to RTU
CCI 2.2 Wireless VHF
ICT 3.1 Substation Automatic systems
Substation power supply
ICT 3.4 NMS (maintenance) Wireless VHF
Reduce of functionality
Interruption of energy supply
MV Customers
Feeder MV for power supply
Environmental conditions
MV pole fell, demadge to FO cable
Interruptions and time Response interference
Communication CI (CCI) 2.1 Transmission network
1.1 Electrical CI (ECI) MV
Interruptions and Interference of SCADA functions
Interruptions and interference of SCADA functions
Interruptions on TCP/IP
Substation power supply
ICT 3.3 NMS Trasmission Comm. Network systems
Interruptions on TCP/IP
ICT 3.2 SCADA MV Wizcon
CCI 2.3 Wire P/P lines
MV power supply to Wizcon fel
Loss of RTU at Indoor trasform.

Thank You!!!

Questions?