Optimal Allocation of Resilience Resources for Strategic Communication-aware Restoration of Smart Distribution Grids

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Outline

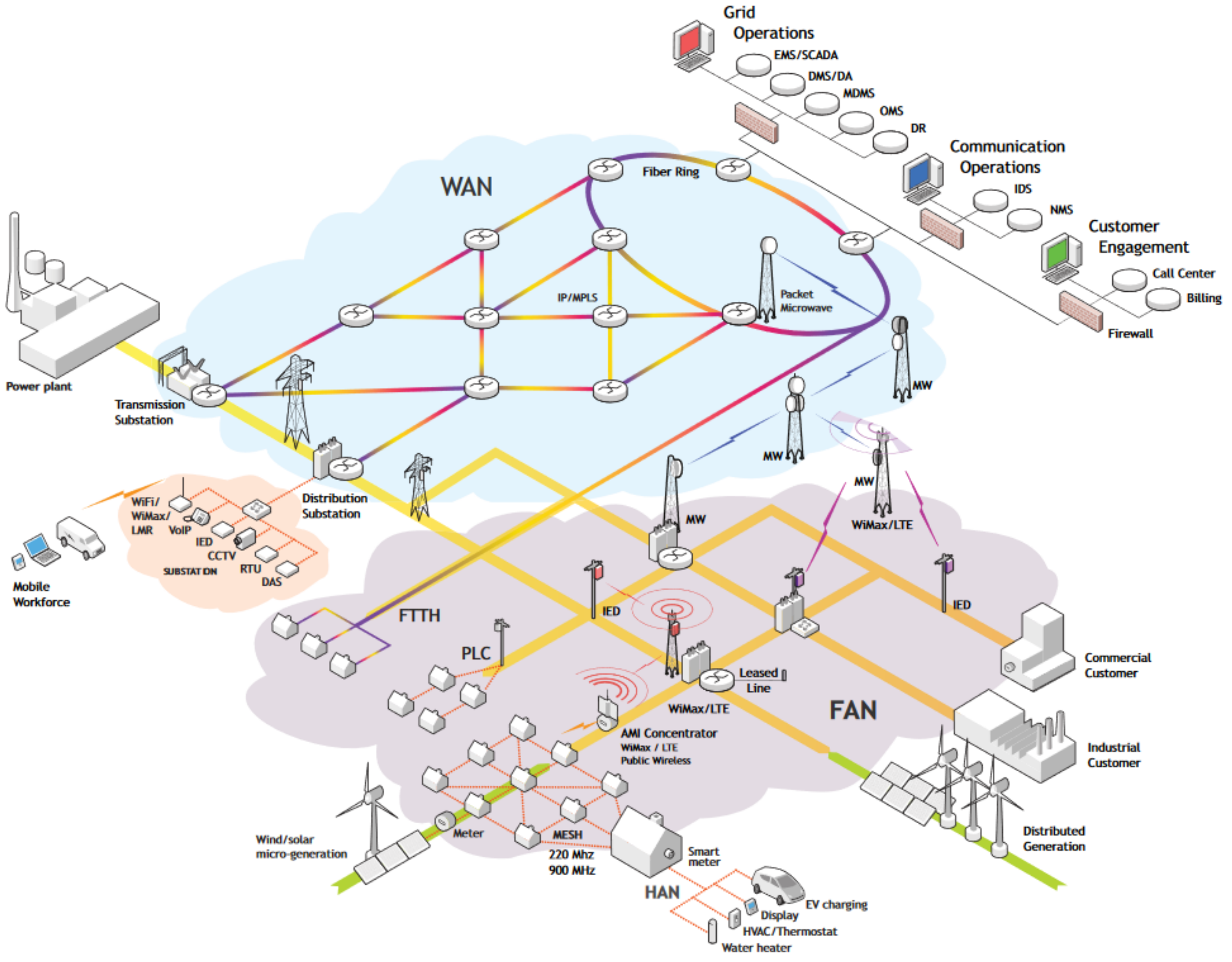
- Introduction
- Problem Description: Distribution System Restoration
- System Model
- Simulation and Results
- Conclusion

Introduction

Introduction

Smart Grids

- Information and Communication Technologies (ICTs) are present at all levels of the smart grid
- Heterogenous technologies serve different functions of the grid
- Power-ICT interdependencies drive the operation of the power system, especially in case of extreme events



* http://www.smartgrids-cre.fr/media/documents/Alcatel-Lucent_SmartGrid_Brochure_EN.pdf

Introduction

Smart Distribution Grids

Automatic Metering Infrastructure	Distribution Automation	Grid Management	Electrical Mobility	Workforce Enablement
Smart Meters	FLISR	Grid Optimization	PEVs	Local Device Management
Service Management & Demand Response	Volt/VAR Regulation	Grid Stabilization	Smart Charging	Field Intervention
	Monitoring, Control and Protection	DG/DER		

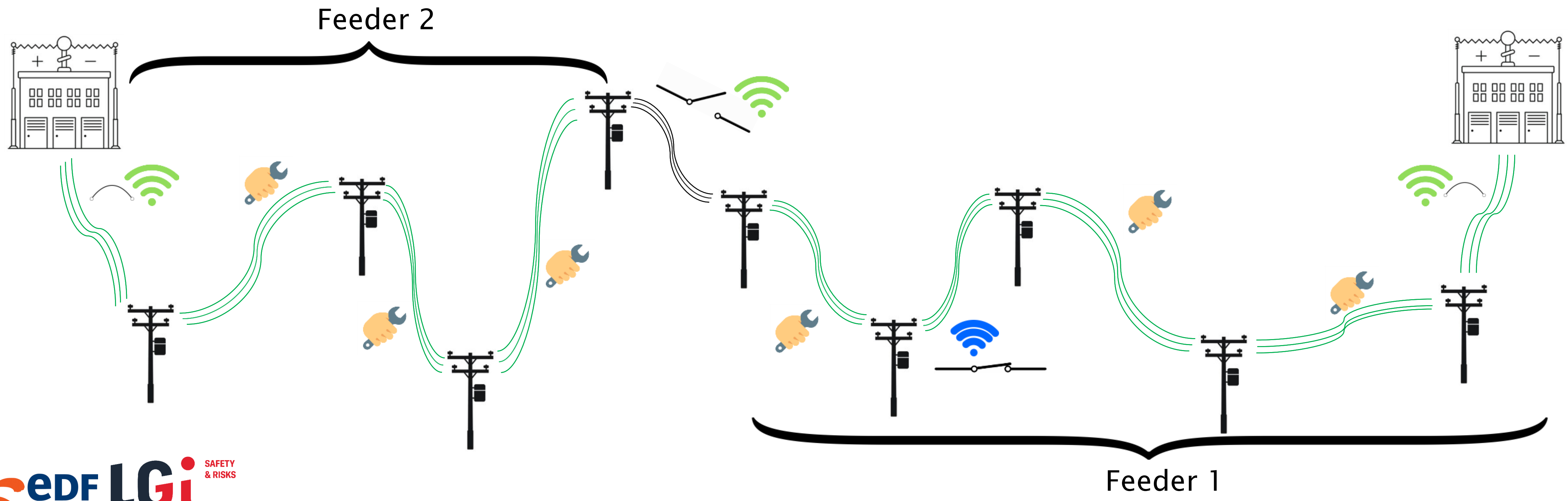
* https://www.cisco.com/c/en/us/td/docs/solutions/Verticals/Utilities/FAN/2-0/CU-FAN-2-DIG/CU-FAN-2-DIG1.html

Problem Description

Problem Description

Operation of the Distribution Grid

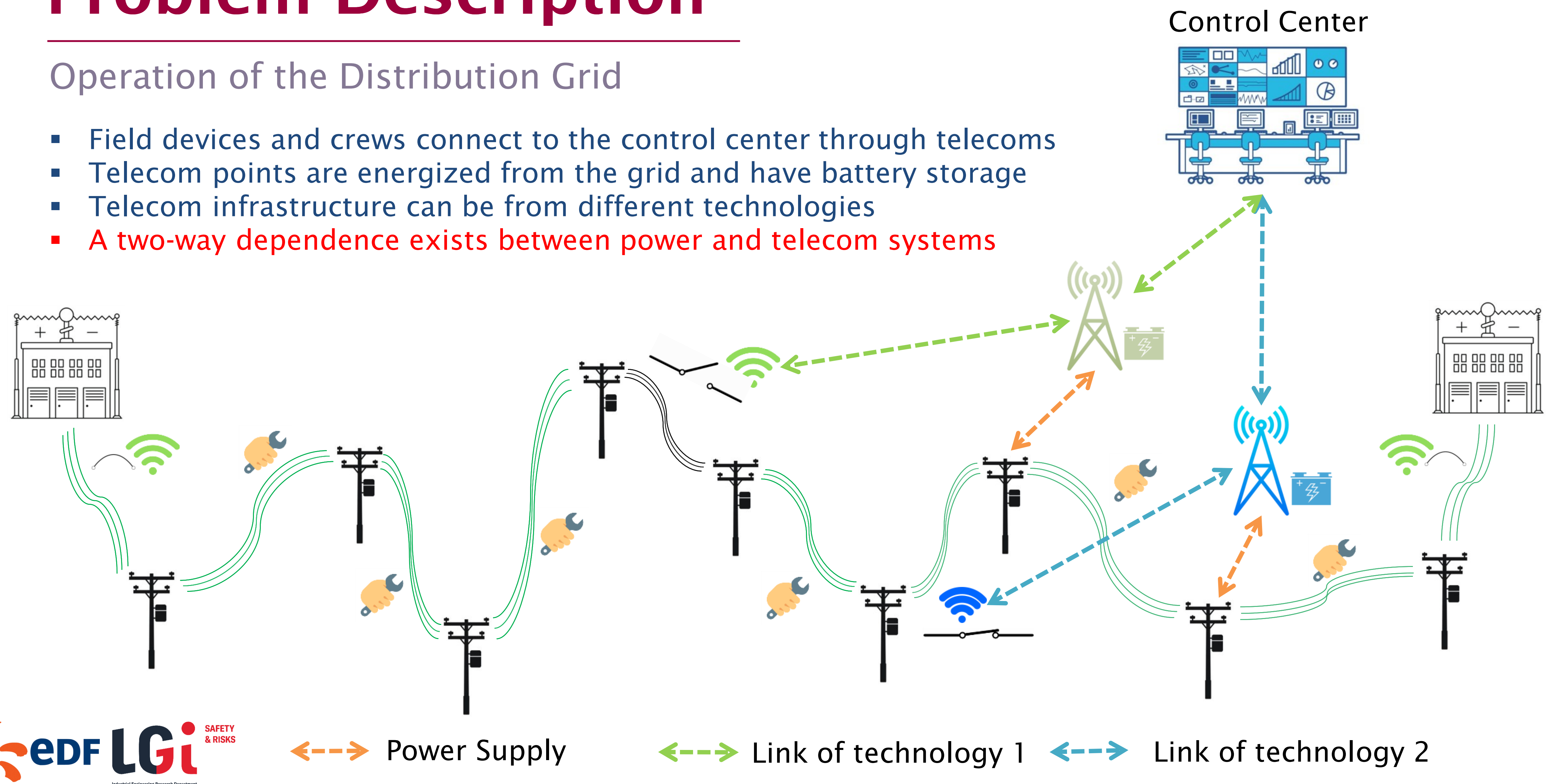
- The distribution grid is a meshed network, which is operated radially
- Power lines have either manual or remote switches
- Two feeders are joined with a normally open Tie-switch
- Field devices connect to the control center



Problem Description

Operation of the Distribution Grid

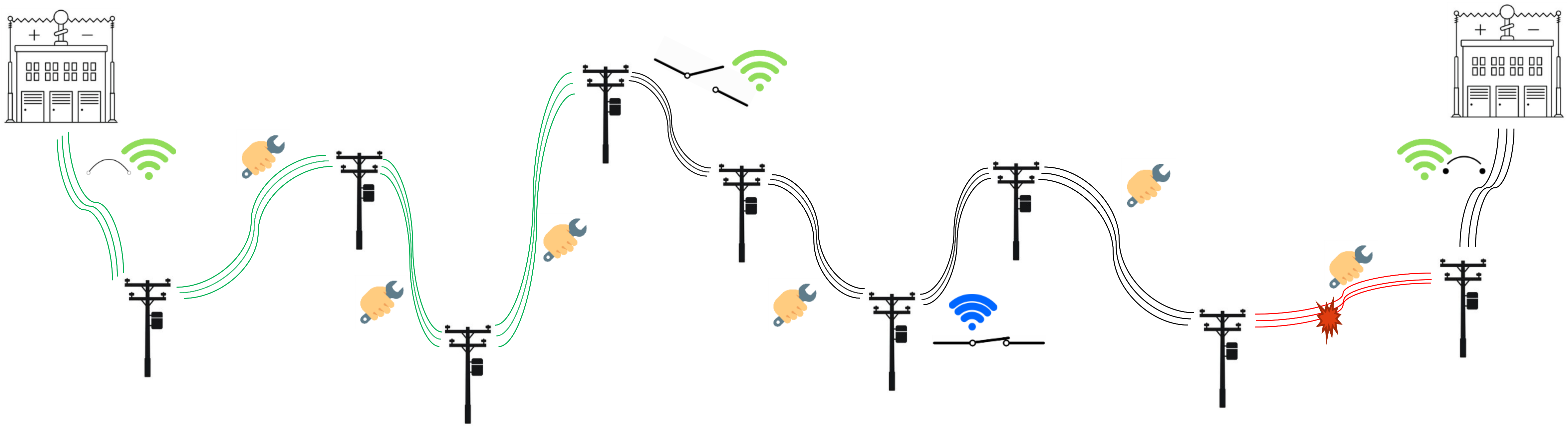
- Field devices and crews connect to the control center through telecoms
- Telecom points are energized from the grid and have battery storage
- Telecom infrastructure can be from different technologies
- A two-way dependence exists between power and telecom systems



Problem Description

Distribution Service Restoration

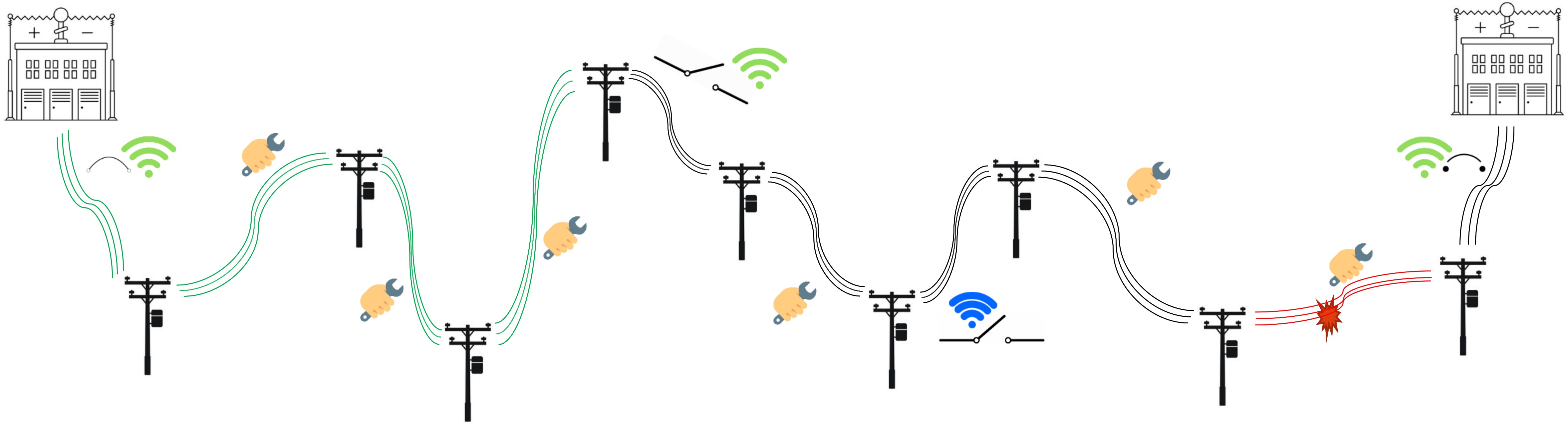
- Detect (and locate) failures



Problem Description

Distribution Service Restoration

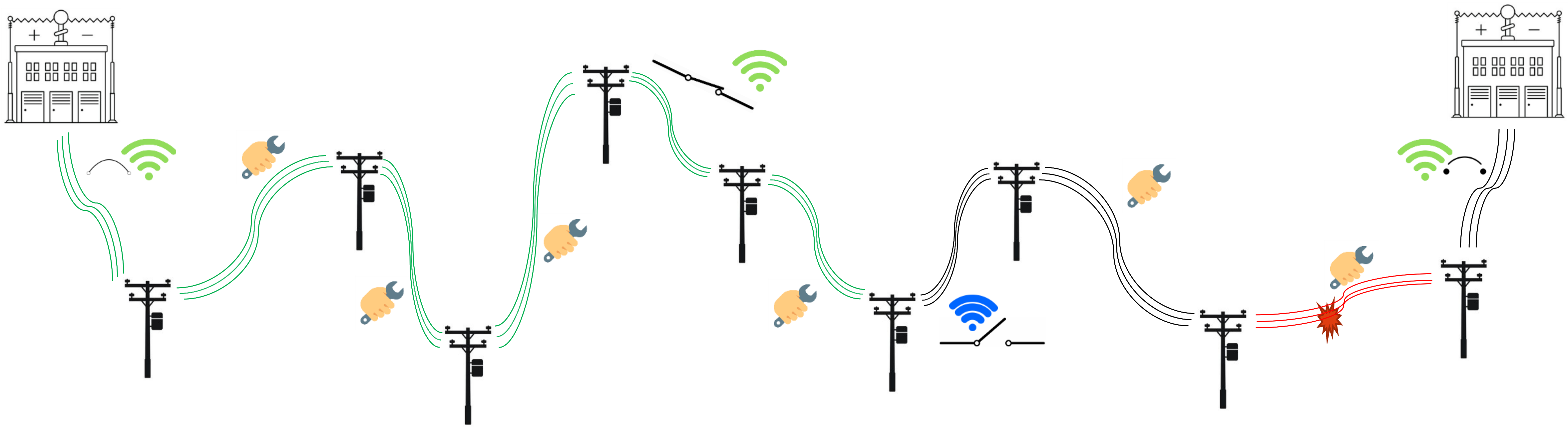
- Detect (and locate) failures
- Isolate the failures to the smallest allowable segment of the grid



Problem Description

Distribution Service Restoration

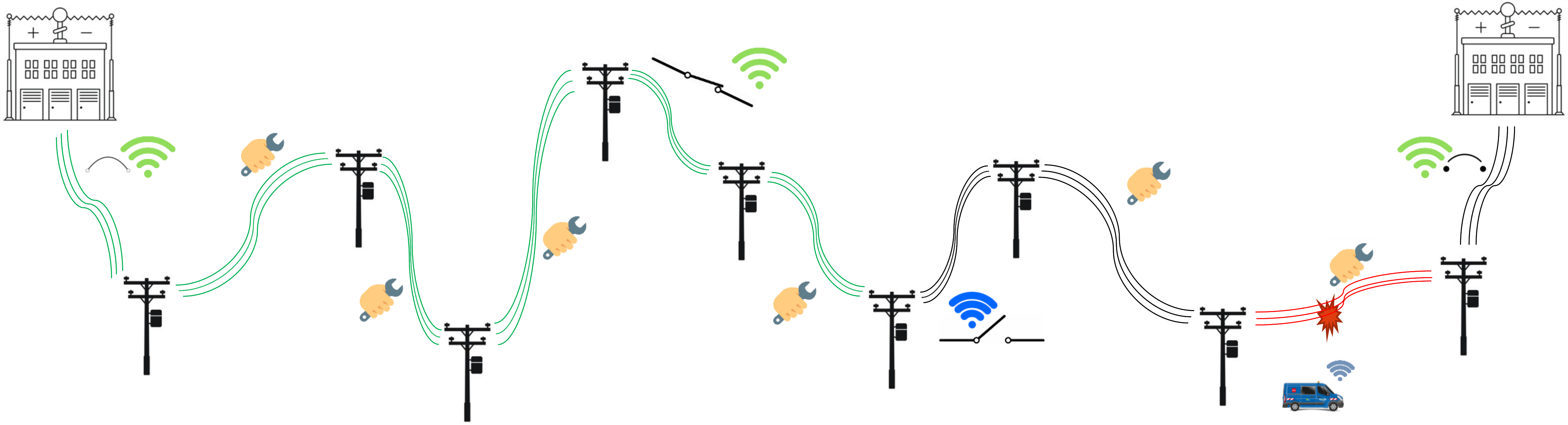
- Detect (and locate) failures
- Isolate the failures to the smallest allowable segment of the grid
- Target: Restore as much service as possible while failures are isolated



Problem Description

Distribution Service Restoration

- Detect (and locate) failures
- Isolate the failures to the smallest allowable segment of the grid
- Target: Restore as much service as possible while failures are isolated
- Actions: Use available resources to recover unserved loads, e.g., remote/manual switches, repair crews, distributed generators

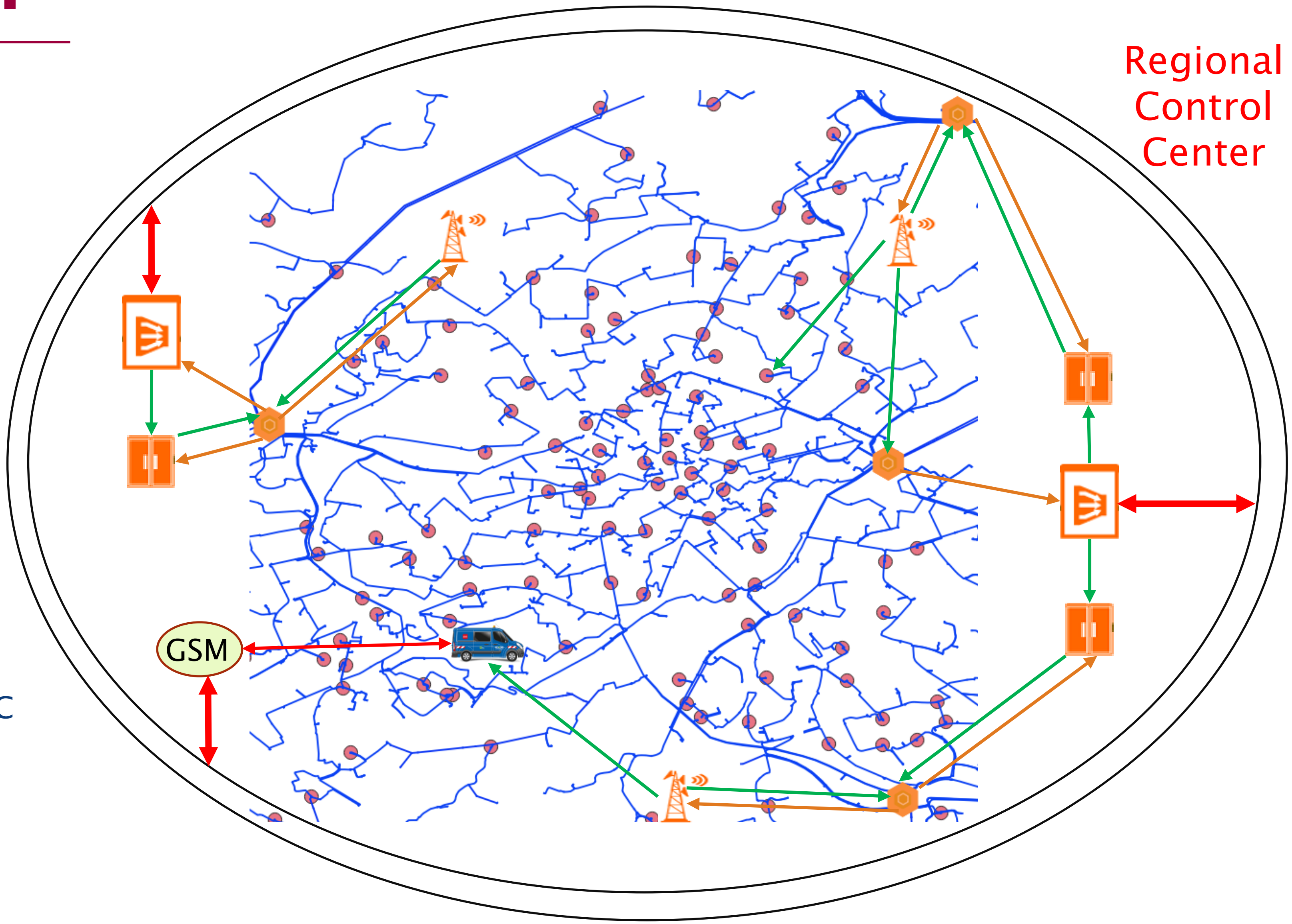


System Model

System Model

Network Setting

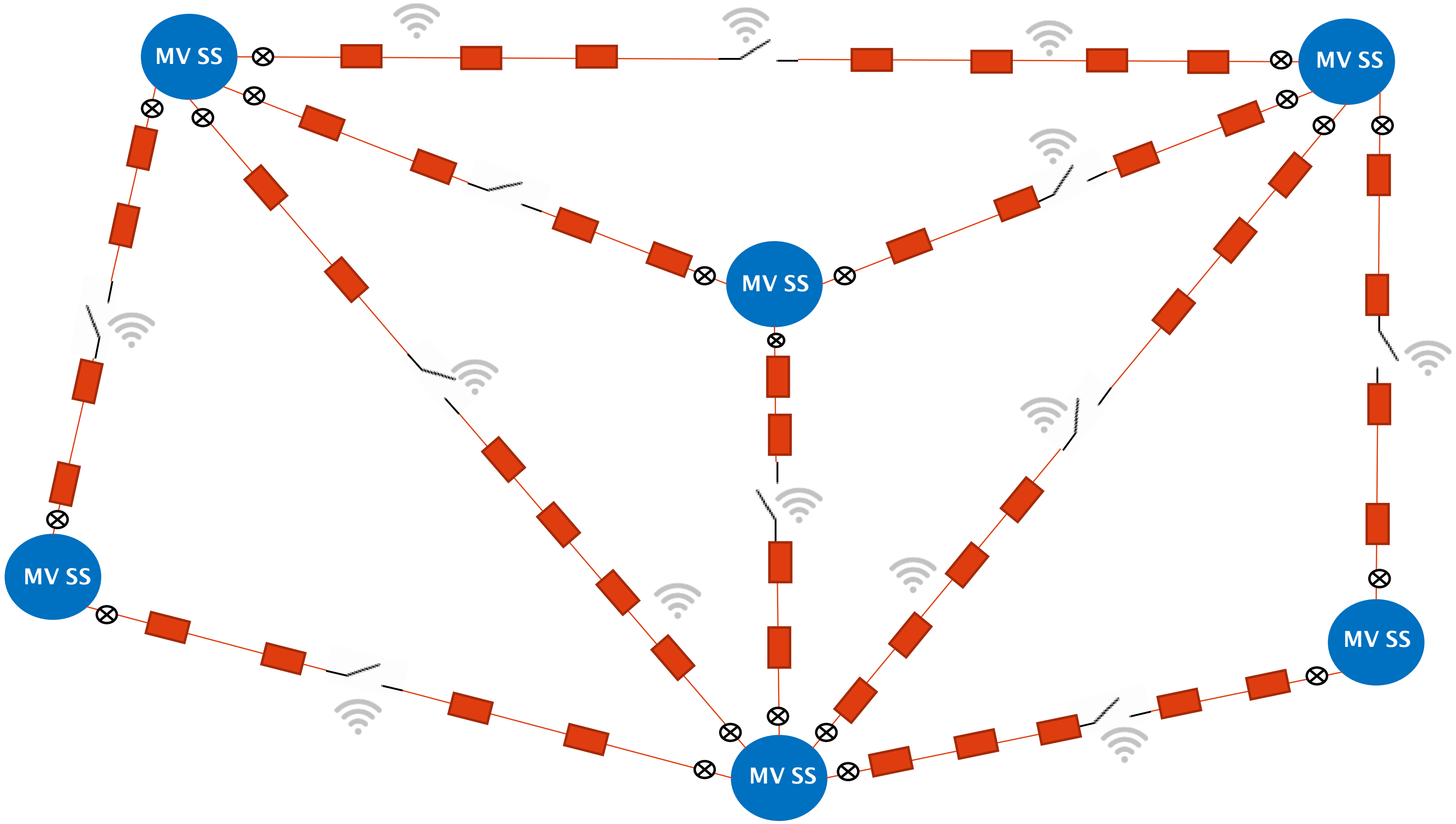
- HV-MV or MV Substation
- Switches
- Wired aggregation point
- Wired access point
- Wireless site - Secondary
- Power supply
- Telecom service
- Information Exchange with CC
- Intervention Crew



System Model

Network Setting

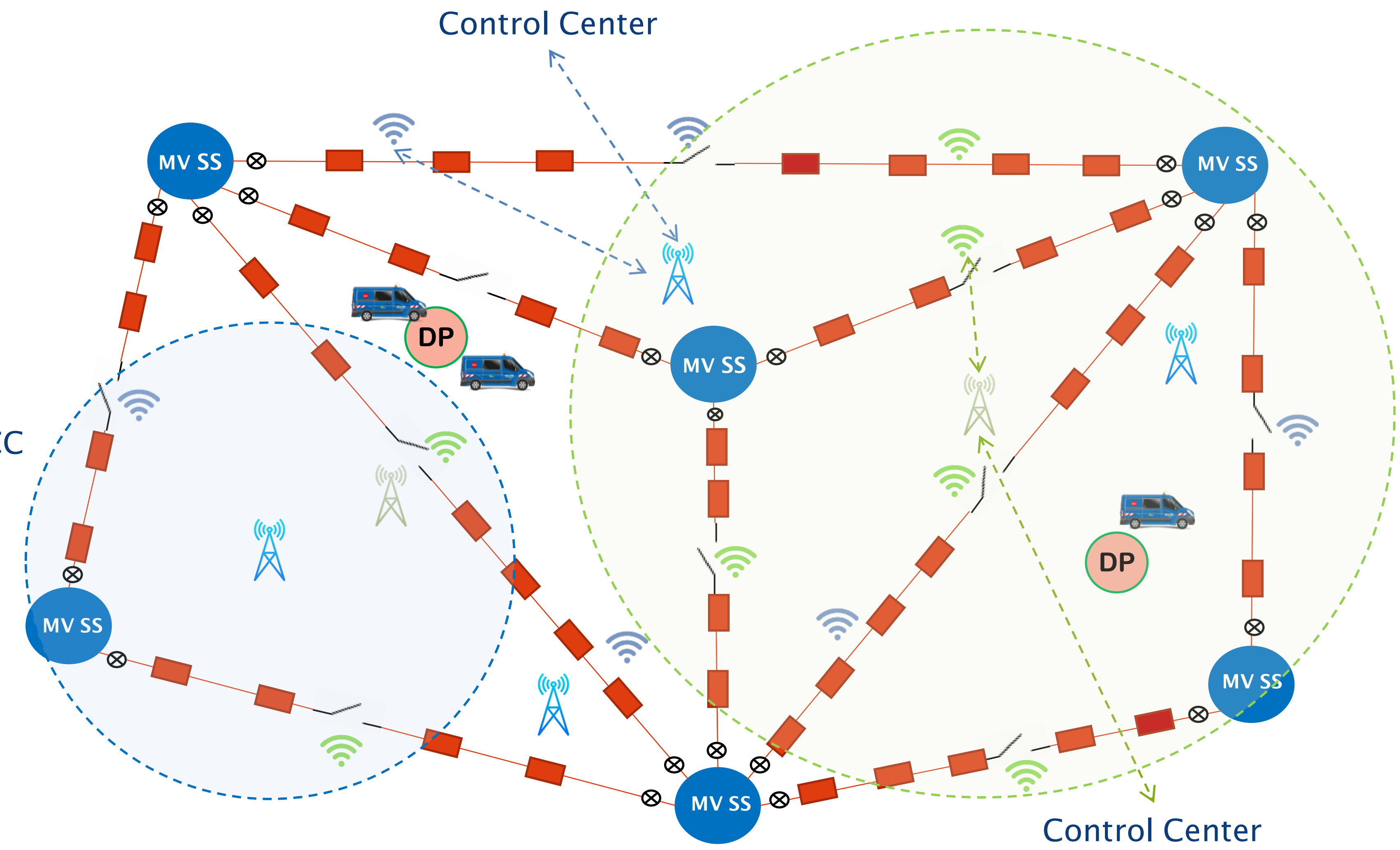
- MV SS — HV-MV or MV Substation
- Load
- Circuit Breaker
- Tie Switch
- Remote-Controlled Switch



System Model

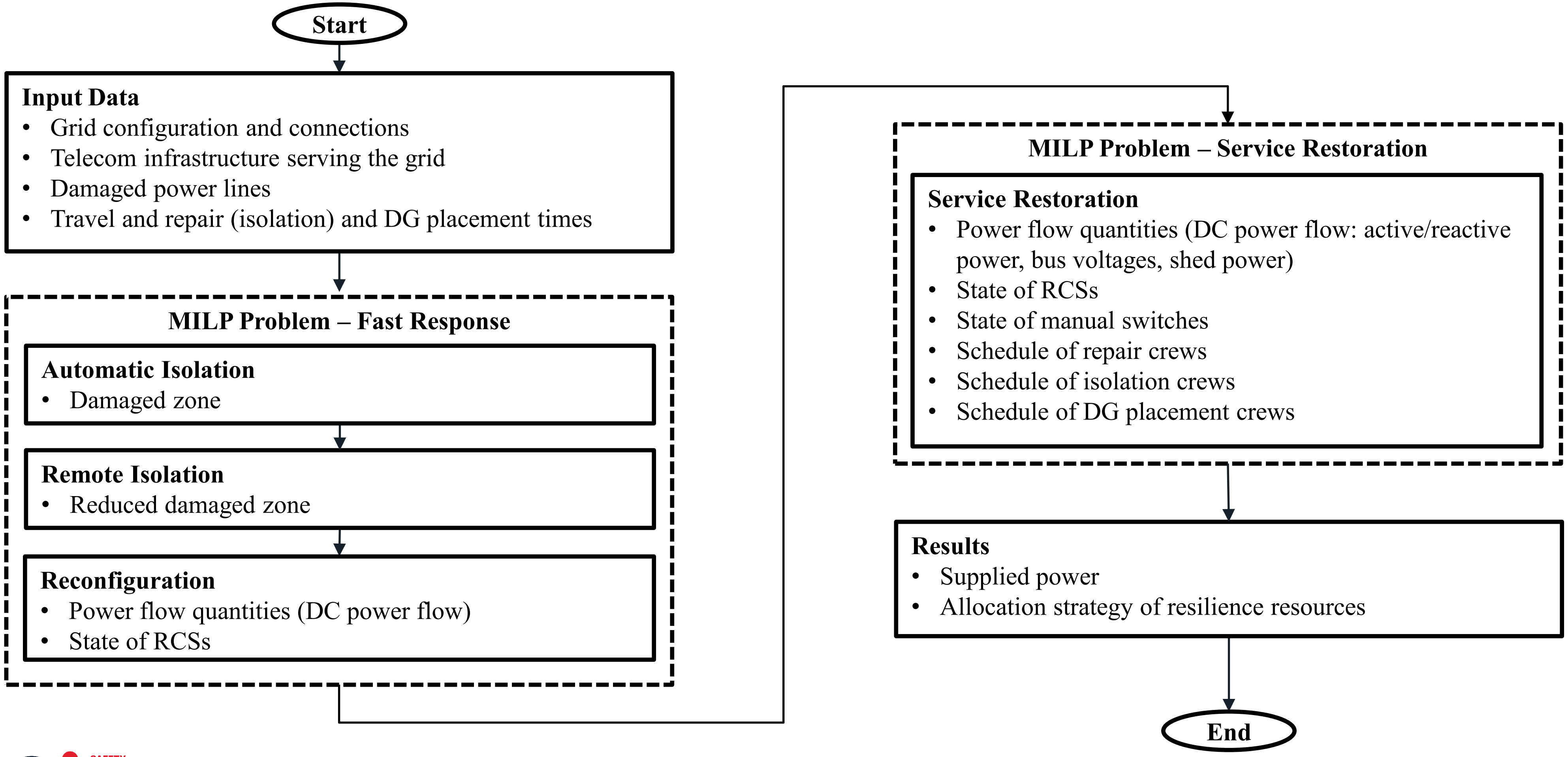
Network Setting

- MV SS — HV-MV or MV Substation
- Load
- Circuit Breaker
- Tie Switch
- Information Exchange with CC
- Remote-Controlled Switch
- Telecom Point
- Intervention Crew
- DP — Crew Depot (or Warehouse)



System Model

Proposed Approach



System Model

Optimization Formulation: MILP

Objective:

$$\min_{p,d,sw,c,a,y,T,E,w'} \left[\alpha \sum_{\forall t} \sum_{\forall i \in N \setminus S} C_i^{ns} \cdot p_{i,t}^{ns} + \beta \sum_{\forall t} \sum_{\forall l \in L} C^{sw} \cdot w_{l,t} + \gamma \left(\sum_{\forall (dp,k,l,t)} C_i^{rc} \cdot rc_{l,t}^{dp,k} + \sum_{\forall (dp,k,l,t)} C_i^{mc} \cdot mc_{l,t}^{dp,k} + \sum_{\forall (dp,k,n,t)} C_i^{gc} \cdot gc_{n,t}^{dp,k} \right) \right]$$

Subject to:

Topological and physical constraints of the grid, Impact of damage scenario, Interdependence constraints

Where:

- $p_{i,t}^{ns}$: Non-supplied power to node i at time t
- a : Availability of line l at time t
- y : Connection state of loads
- p : Active/Reactive power, node voltages
- T : State of telecom services
- sw : State of the switches
- C : various costs
- rc, mc, gc : planning of crews

→ Goal: Find the network configuration and intervention planning that optimize the system resilience with minimal costs

System Model

Key constraints

- Routing and scheduling

$$rc^k_{l,t+\tau} + rc^k_{m,t} \leq 1, \quad \forall m \neq l, \quad \forall \tau : 0 \leq \tau < TT^{rc}_{l,m}$$

$$gc^k_{l,t+\tau} + gc^k_{m,t} \leq 1, \quad \forall m \neq l, \quad \forall \tau : 0 \leq \tau < TT^{gc}_{l,0} + TT^{gc}_{m,0}$$

- Task completion

$$a^{dg}_{n,t} \leq \frac{\sum_{\tau=0}^{t} gc^k_{n,\tau}}{GT_n}, \quad \forall k$$

- Battery of telecom access points

$$E_{i,t} = E_{i,t-1} - p^{disc}_i \cdot \left(1 - y^e_{i,t-1}\right) \cdot b_{i,t-1}$$

- Power supply to telecom points

$$\frac{1}{M} \cdot (1 - f_i) \cdot \left(E_{i,t} + y^e_{i,t}\right) \leq T^e_{i,t} \leq M \cdot (1 - f_i) \cdot \left(E_{i,t} + y^e_{i,t}\right)$$

- Telecom service of power nodes

$$sw_{l,t-1} \leq sw_{l,t} \leq sw_{l,t-1} + ss^c_{k,t} a^e_{i,t}, \quad \forall l \in L^{cb}$$

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Simulation and Results

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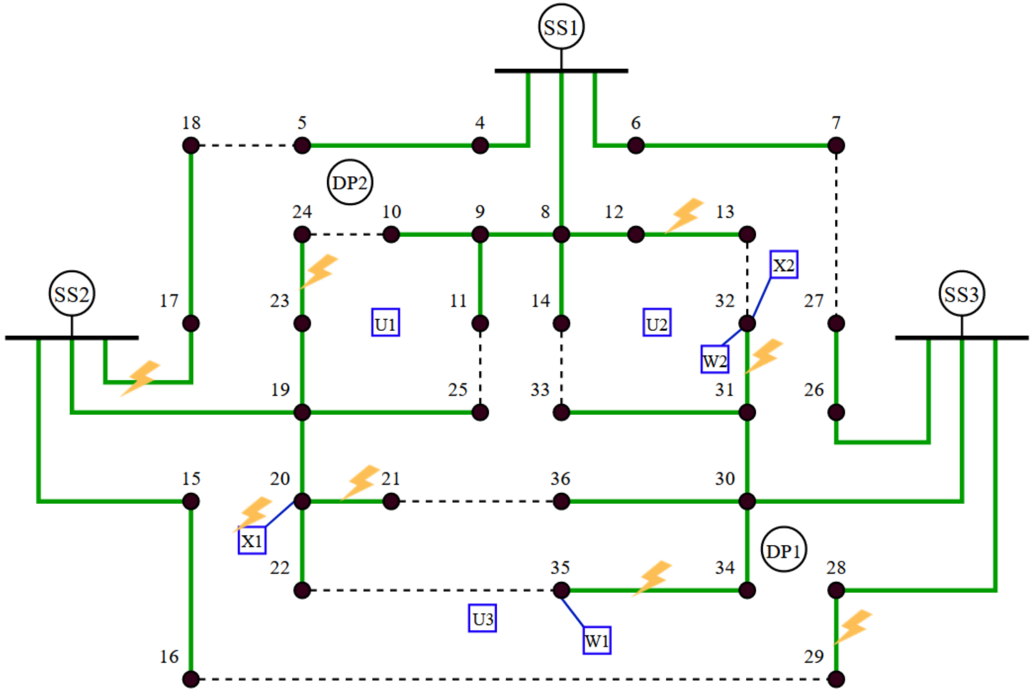
Simulation

Network Setting

- Failure scenario in 7 power lines and one telecom access points (X1)
- Power lines contain either remote or manual switches
- Configuration: 3 HV/MV substations, 33 MV buses, 42 power lines
- Access points have battery capacity of 3 hours

Telecom Point	Number	Power Supply
Aggregation Point	1	Node 9
Fixed Access Point (X)	2	Node 32, Node 20
Wireless Access Point (W)	2	Node 32, Node 35
Utility-owned telecom point (U)	3	
Depot	2	



Depot	Repair Crews	Manual Isolation Crews	DG Placement Crews
DP1	2	1	1
DP2	2	1	1

Results

Result 1

- Only automatic recloser, circuit breakers and remote switches are used for fast reconfiguration
- The optimization is conducted in the reconfiguration phase (*t = D*)
- The result from this stage is taken as input to the restoration stage
- Networks with underground (U) lines perform better due to improved isolation

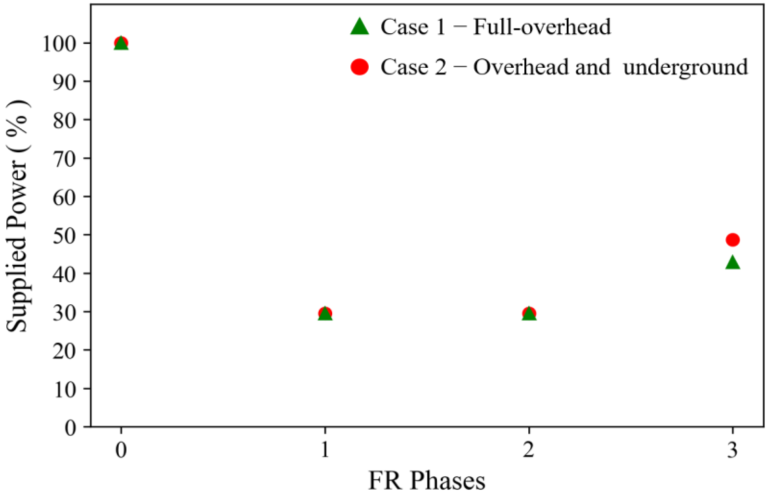


Figure 1. Evolution of supplied power during fast response

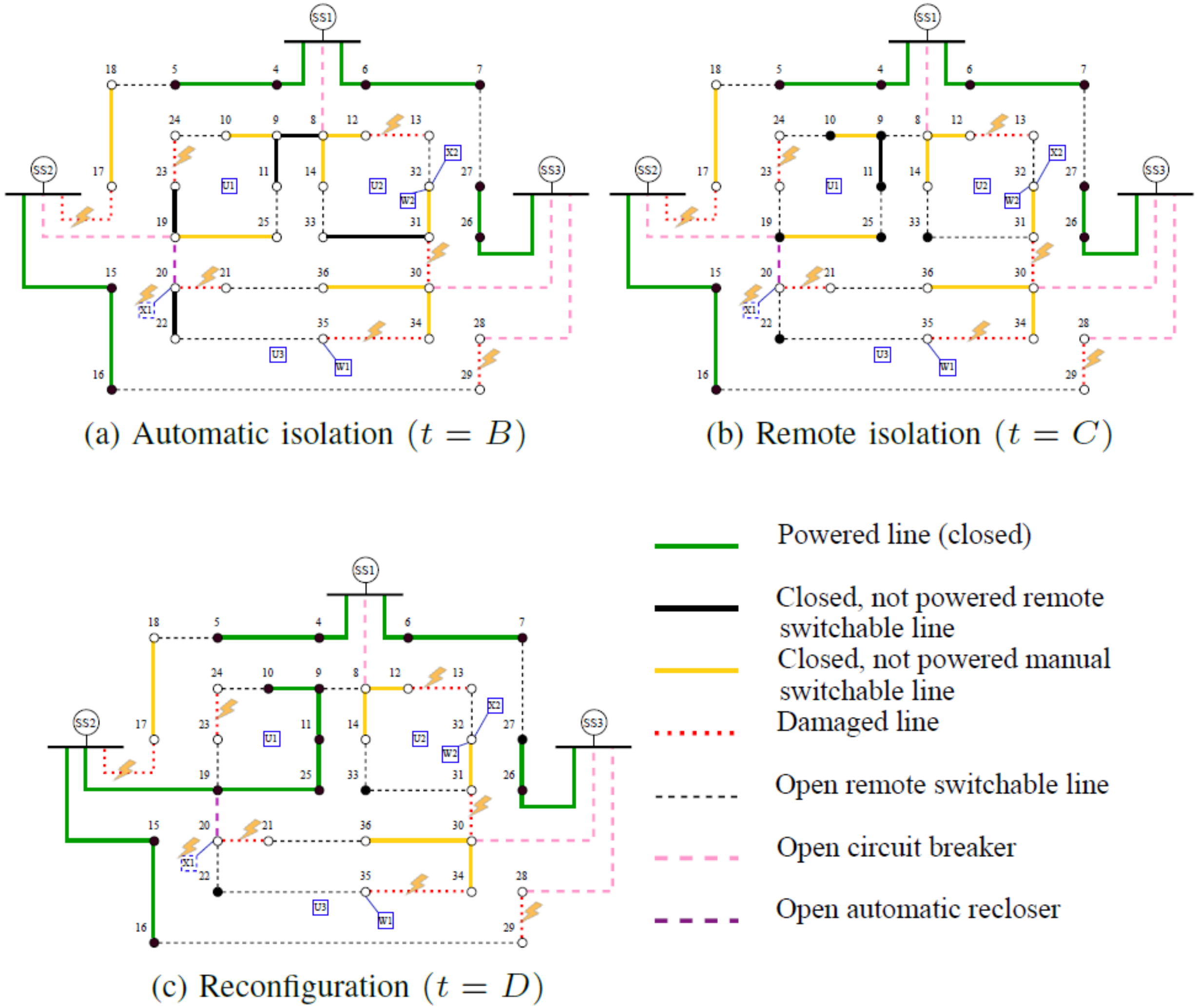


Figure 2. Illustration of fast response phases

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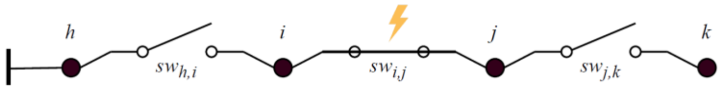
Results

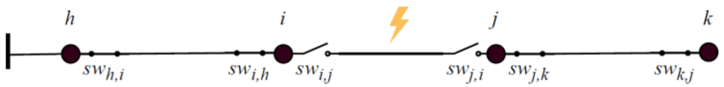
Result 2

- Neglecting the state of the telecom infrastructure overestimates the recovery capabilities
- Considering the evolution of telecom state during an extreme event and the coordination of resilience levers makes it possible to follow a better recovery strategy
- Networks with underground (U) lines once again perform overall better due to improved isolation

Overhead lines



Underground lines



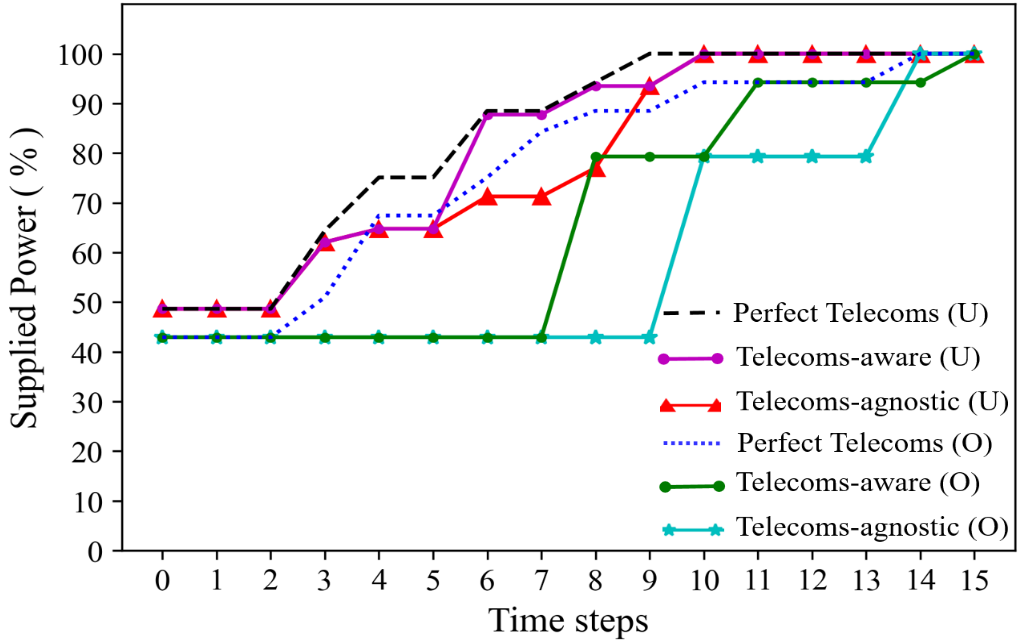


Figure 3. Evolution of supplied power during service restoration

Results

Result 2

- The model tends to prioritize critical telecom points, which contribute to service restoration in subsequent time periods

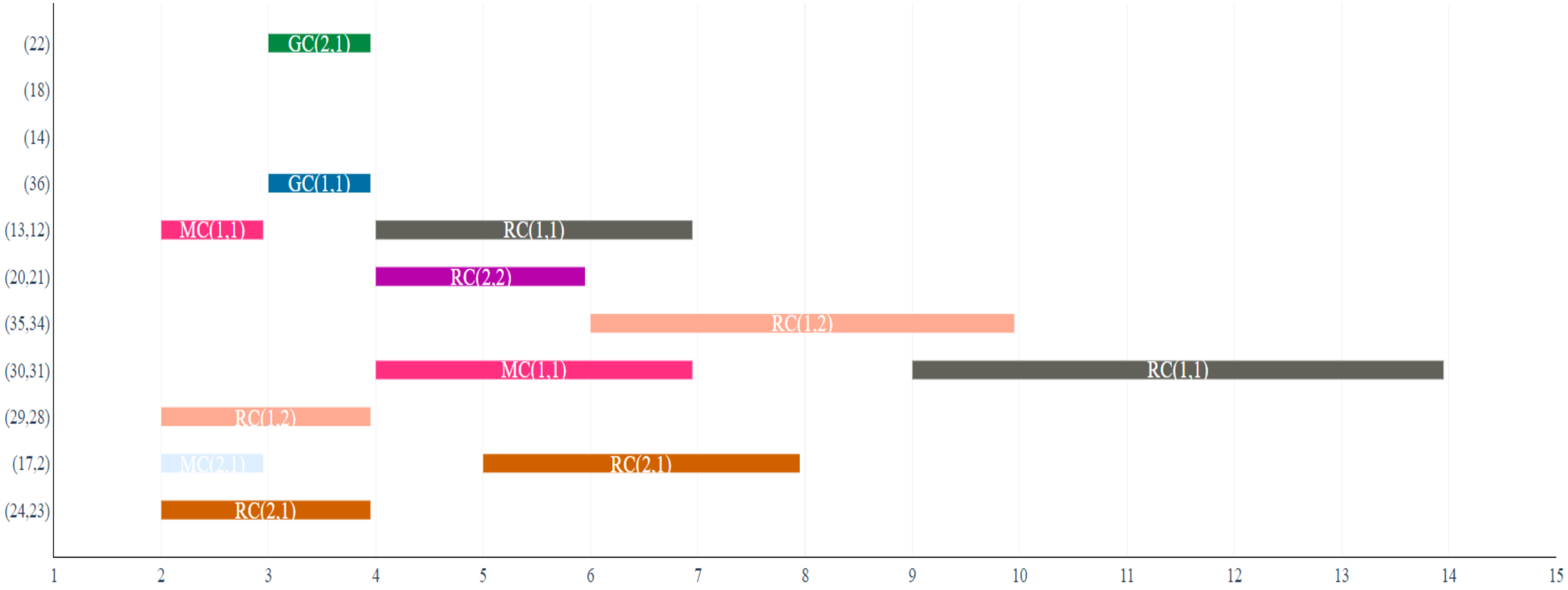
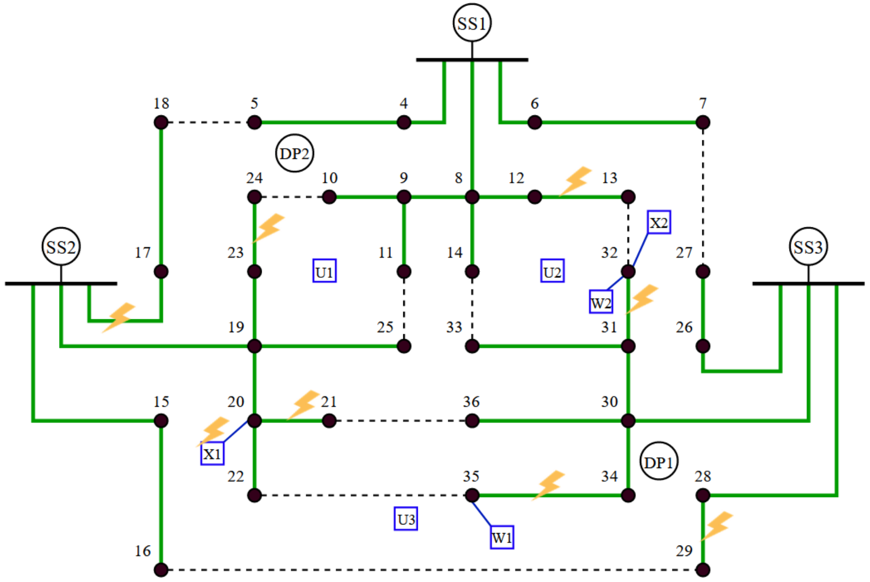


Figure 2. Crew Schedule – Telecom-agnostic case



Depot	Repair Crews (RC)	Manual-switching Crews (MC)	DG Placement Crews (GC)
DP 1	RC(1,1) RC(1,2)	MC(1,1)	GC(1,1)
DP 2	RC(2,1) RC(2,2)	MC(2,1)	GC(2,1)

Results

Result 2

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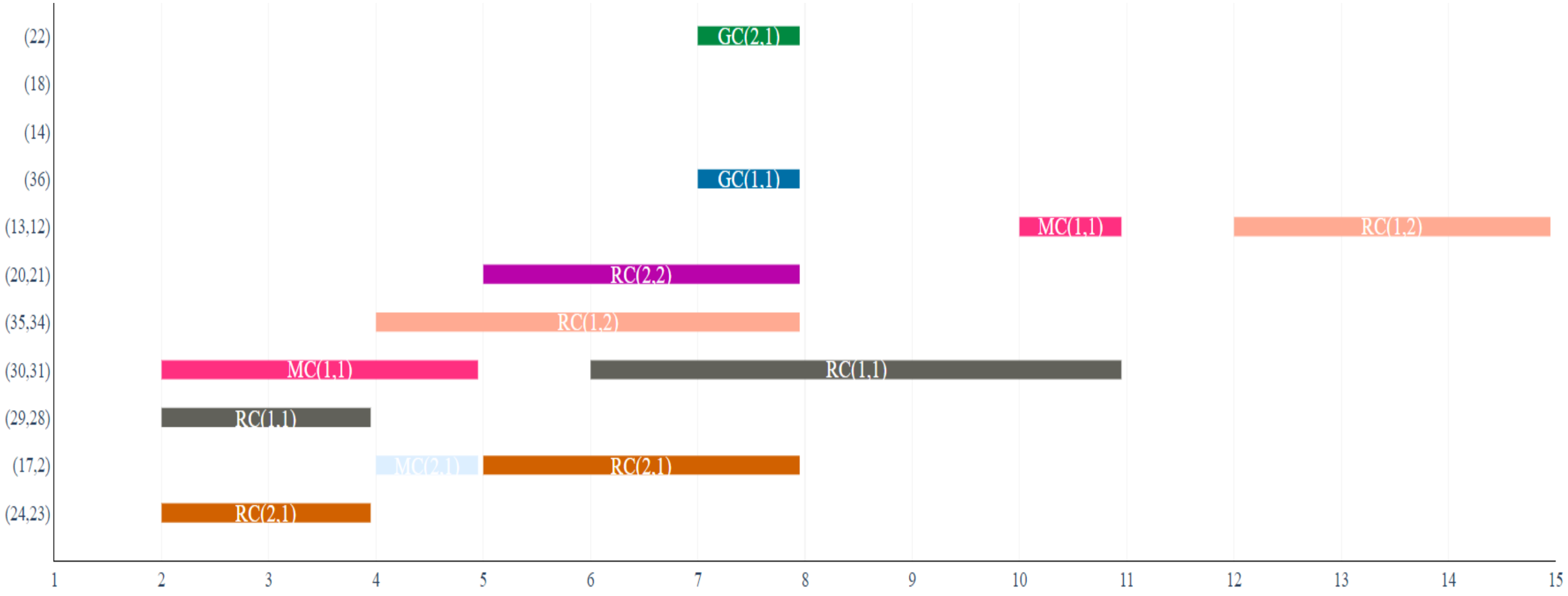
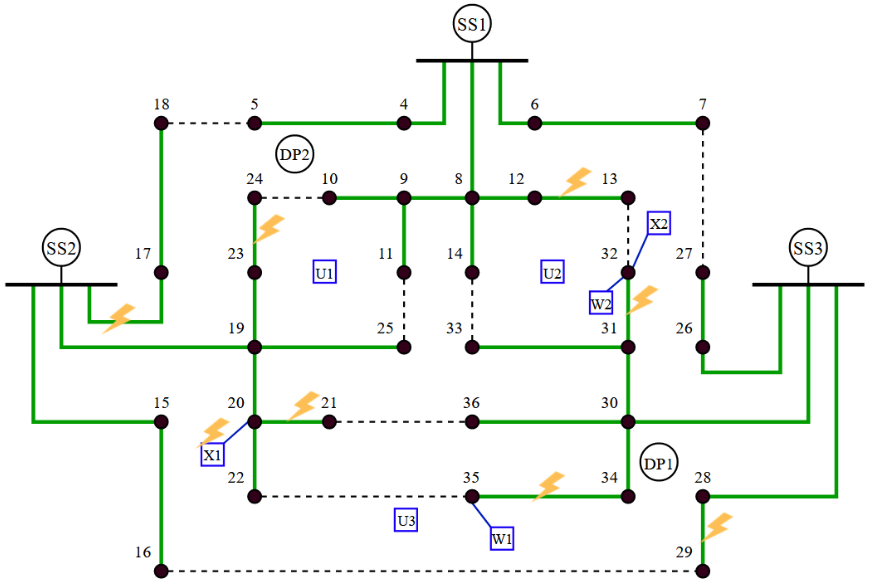


Figure 3. Crew Schedule – Telecom-aware case



Depot	Repair Crews (RC)	Manual-switching Crews (MC)	DG Placement Crews (GC)
DP 1	RC(1,1) RC(1,2)	MC(1,1)	GC(1,1)
DP 2	RC(2,1) RC(2,2)	MC(2,1)	GC(2,1)

Conclusion

Conclusion

Major contributions

- A DSR co-optimization model is proposed to find optimal recovery strategies while leveraging information on the availability of telecom assets
- The co-optimization captures various interdependencies: between power and ICT networks, among resilience resources, and within public-private telecoms
- Different grid architectures including the two broad families of overhead and underground networks are considered, which allows minimal model changes for configuration evolution
- A simplified formulation is proposed for radiality conditions, and a realistic multi-feeder network is constructed to validate the proposed model.
- Fast moving isolation crews are introduced to allow highly flexible recovery

Conclusion

Current Work

- The power flow model is linear, which is very informative for the “system level” view required for resilience assessment. Nevertheless, for a finer description of the interdependent network, the model must above all be completed for the telecom layer

- Introduce telecom intervention crews into the model

- The complexity of the model remains acceptable (in the order of a thousand nodes), but can be enhanced by working on a low-complexity solution for the MILP

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Related Works

References

- Youba Nait Belaid, Yi-Ping Fang, Zhiguo Zeng, Anthony Legendre, Patrick Coudray, and Anne Barros. "Resilience-based Optimization of Wide-Area Control in Smart Distribution Grids". IFAC-PapersOnLine, volume 55, January 2022.

- Youba Nait Belaid, Anne Barros, Yiping Fang, Zhiguo Zeng, Anthony Legendre, and Patrick Coudray. "Enhanced Power and Communication Modeling in Cyber-Physical Distribution Grids for Resilience-based Optimization". In European Safety and Reliability Conference (ESREL), Dublin, Aug. 2022.

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Thank you for your attention

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