Optimal Relocation of Virtualized PDC in Edge-Cloud Architectures under Dynamic Latency Conditions

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Outline

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Problem Definition

Problem Statement of Synchrophasor Networks

- Phasor Measurement Units (PMUs)
  - Voltage and Current Phasors
  - Frequency computation
  - GPS timestamp
  - Up to 120 measurements per second
- Phasor Data Concentrators (PDCs)
  - Physical or virtualized devices
  - Concentrate, aggregate and forward measurements
  - Disregard measurements arriving after wait time
- Synchrophasor based applications demand:
  - Regardless network conditions
  - Measurements to arrive with minimum delay.
  - Measurements not to be disregarded.

Static PDC setups may not be able to satisfy these constraints

State of the art

- Optimization of PDC wait time according to the network latency variations
- SDN controllers to reroute the PMU streams to different PDCs

Proposed Solution

- Deploys virtualized PDC instances
- Continuously monitors the network performance
- Reacts when the network constraints are violated
- Optimally relocates the virtual PDCs instances

Synchrophasor Network Latency

Measurement transmission latency (λ_m):

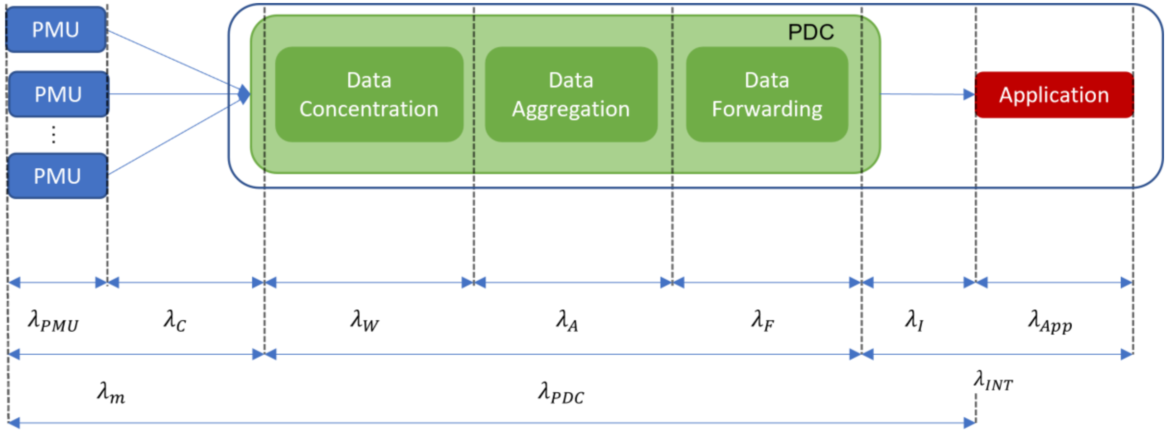
- From timestamping (λ_{PMU}) at the PMU until the reception at the PDC (λ_C)
- λ_{PMU} is considered constant
- λ_C varies according to network congestion

PDC latency (λ_{PDC}):

- From the reception of the first measurement, until the transmission of the aggregated measurements stream
- λ_A and λ_F are considered constant
- Absolute and relative wait time modes

Target application latency (λ_{INT})

- Transmission delay (λ_I) and the target application processing delay (λ_{App})
- λ_I is omitted when the App is collocated with the vPDC



Synchrophasor Delay

Fulfillment of two requirements

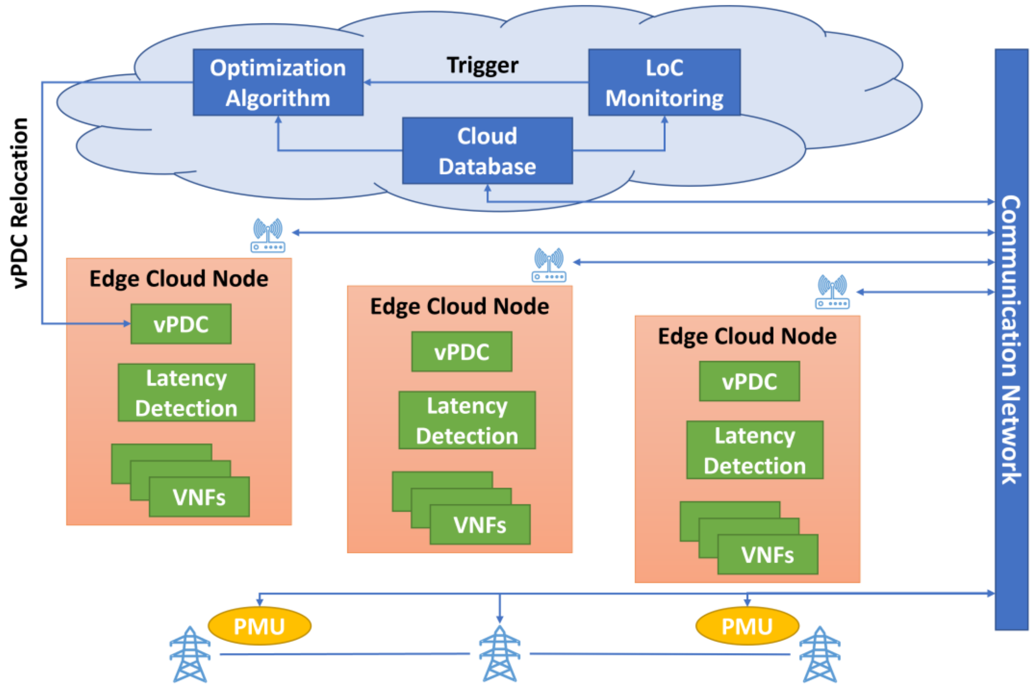
- End-to-end latency must be below a specific threshold.
- Level of Completeness (LoC) must be above a minimum value.

Proposed Framework

- Setup assumptions
  - The power grid is equipped with a number of optimally placed PMUs providing full observability.
  - Each node of the system is equipped with general purpose hardware resources with virtualization and edge-cloud capabilities, while GPS modules are used to facilitate universal time synchronization.
  - A wireless network interconnects the nodes, making the PMUs observable from every node where a vPDC could be deployed.

- Framework consists of:
  - LoC Detection Component
  - Latency Detection Component
  - Optimization Algorithm

- The procedure is centrally orchestrated on the grid operator's cloud, where the needed metrics are collected, stored and processed.



LoC and Latency Detection

LOC DETECTION

- Triggers the Optimization Algorithm.
- Continuously monitors the LoC ratio at the nodes which host the vPDC instances.
- Emits a relocation signal if LoC remains below the application's threshold for a predetermined time window (detection window).
- This detection window is reconfigurable and determines the sensitivity of the relocation procedure
- Needs to be immune to transient changes, yet fast enough to prevent the loss of measurements.

LATENCY DETECTION

- Provides as input to the optimization algorithm (One Way Delay – OWD)
- The nodes are equipped with GPS modules to be synchronized with the same master clock as the PMUs.
- OWD is calculated as the difference between a measurement's timestamp and the time of its arrival at the target node.
- A sliding window is used to filter out random latency spikes, calculating the mean value of OWD measurements for each route.

Optimization Algorithm

- Determines the minimum number and location of vPDCs in order to meet the application's requirements.
- Uses the maximum permitted latency (maxLatency parameter) to prune the searching space of the graph examined.

$$s_{i,j} = \begin{cases} 1, & \text{if } i = j \\ 1, & \text{if } latency\{i,j\} \leq maxLatency \\ 0, & \text{otherwise} \end{cases}$$

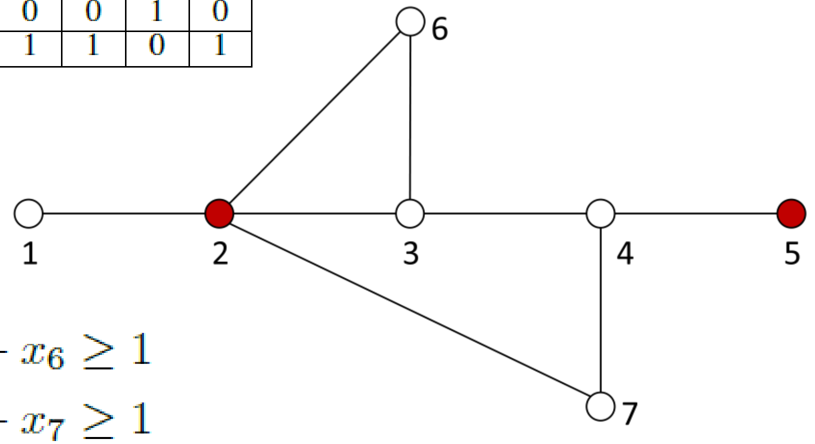
$$\begin{aligned} \text{minimize} \quad & \sum_{i=1}^{N} x_i \\ \text{subject to} \quad & S \times X \geq b \\ & x_i = \{0,1\} \\ & b = [1,1,...,1]^T_{1\times M} \end{aligned}$$

- The S matrix is the observability matrix. The X matrix incudes the decision variables xi for each node. The b matrix is full of ones, since in every PMU neighborhood must be at least one vPDC.

maxLatency equals to 10ms

Distance Matrix		Graph Nodes						
		1	2	3	4	5	6	7
PMU Nodes	2	5	0	5	11	15	3	12
	5	12	15	4	8	0	14	6

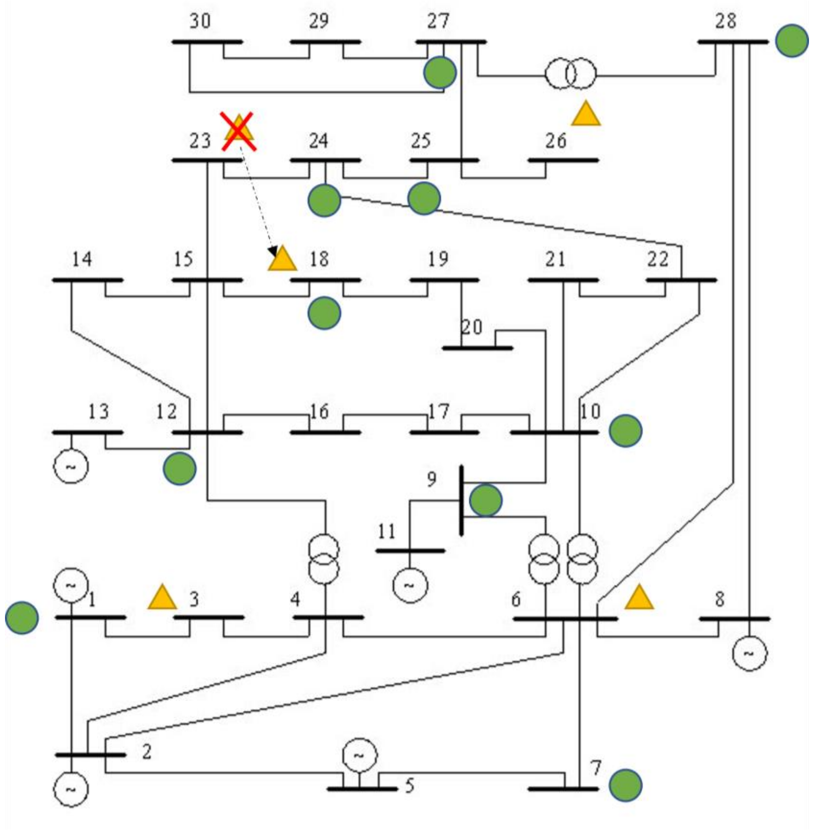
S Matrix		Graph Nodes						
		1	2	3	4	5	6	7
PMU Nodes	2	1	1	1	0	0	1	0
	5	0	0	1	1	1	0	1



$$x_1 + x_2 + x_3 + x_6 \geq 1$$

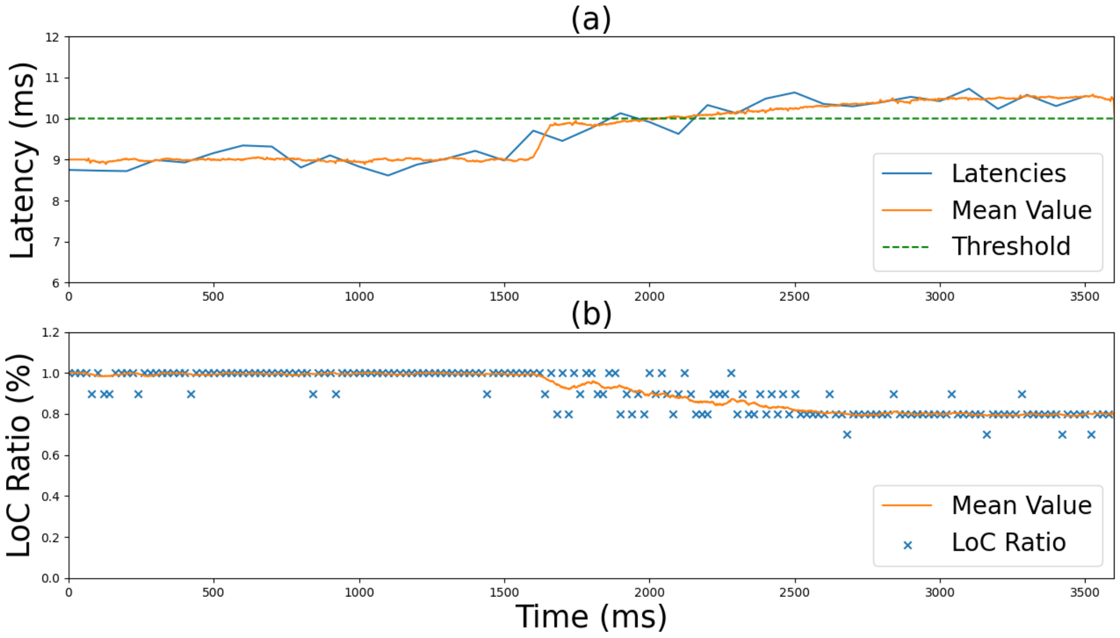
$$x_3 + x_4 + x_7 \geq 1$$

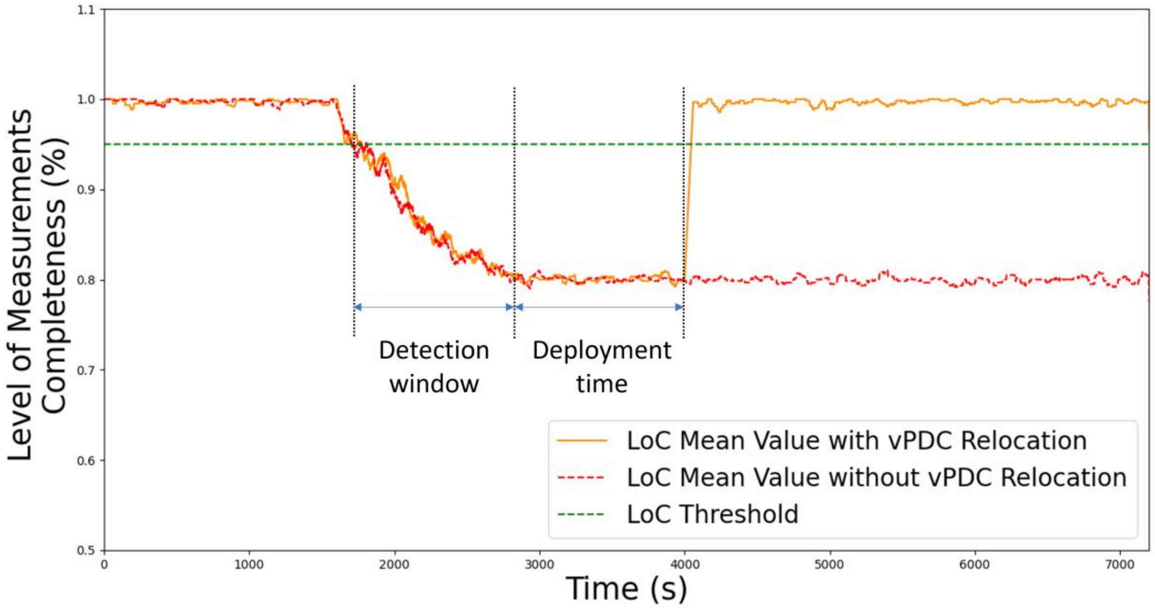
Experimentation and Results



- IEEE 30-Bus test system with 10 PMUs (green circles) are placed optimally,
- Local control operation cohosted with the vPDC (i.e., filtering for voltage spikes identification), demanding
  - maximum network latency below 10ms
  - minimum LoC above 95%
- LoC is measured at the expiration of each vPDC wait time (10ms interval), while OWD is measured at 100ms intervals
- Initial deployment of 4 vPDCs (nodes 3, 6, 23, 26).
- The deployment of a new service, sharing the same network resources, leads to network congestion and to an increased latency at the impacted communication channels.

Experimentation and Results





Conclusion

- Synchrophasor deployments with wireless connectivity are prone to network latency
- Deployment of new applications may lead to violation of network related KPIs, that cannot be resolved with static setups
- In this work, we presented an NFV compliant framework, which:
  - monitors the performance of the target application over time
  - reacts when the LoC ratio indicator, falls below a predefined threshold.
  - provides “self-healing” capabilities to the synchrophasor network
- The reaction to changes of proposed solution is limited by the lengthy deployment and migration times of new vPDC instances, even though the detection is rapid enough.
- Faster deployment times would allow better responsiveness and adaption to changes that happened throughout the process.
- Advances in reliable wireless communication networks (5G Stand Alone networks) and virtualization technologies are expected to reduce deployment times and facilitate the adoption of our framework by power grid operators.

Questions?
Thank you!

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