Opportunistic Hybrid Communications Systems for Distributed PV Coordination

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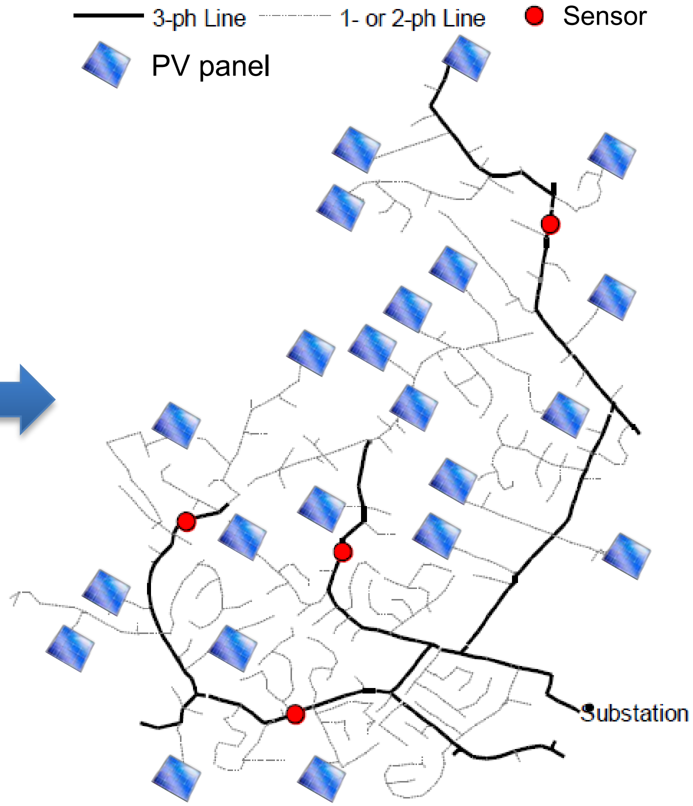
NREL/PR-5D00-71282

Motivation

Current Status

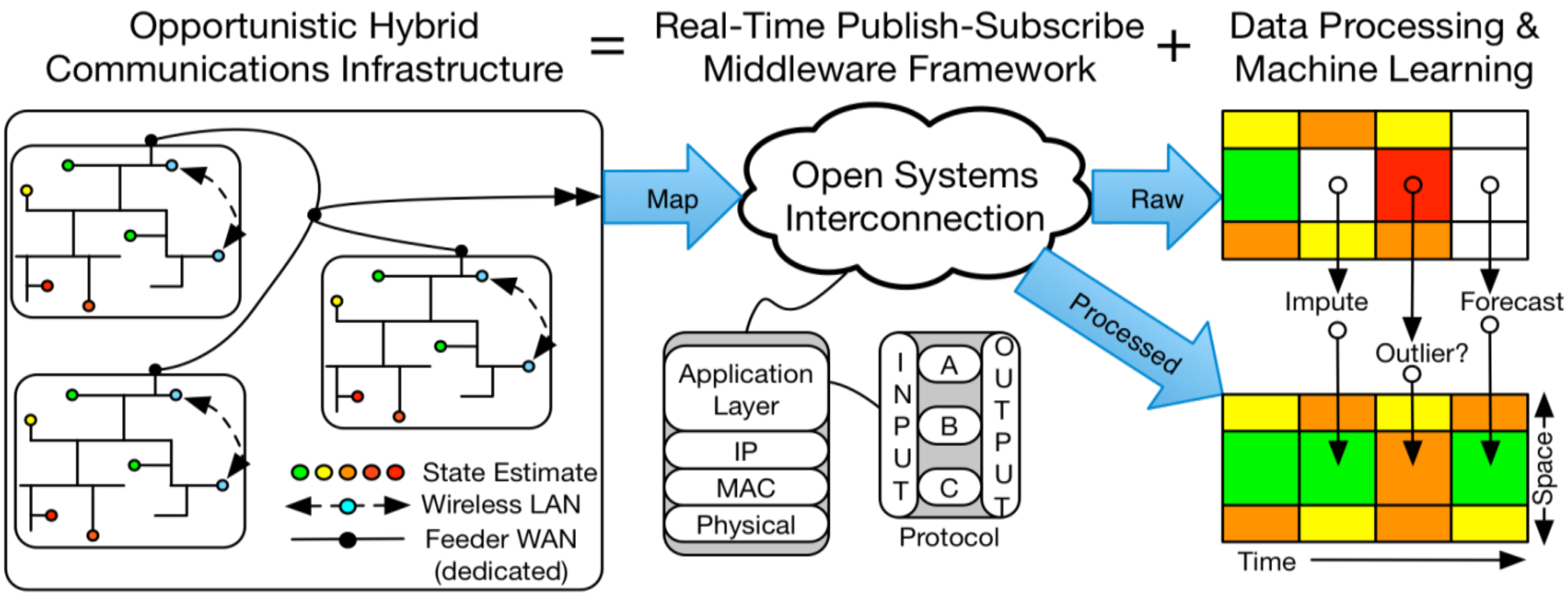
- Lack of sensors in distribution grids
- Limited communication infrastructure in distribution grids
- No access to high-resolution PV generation data for DSO/TSO
- No access to high resolution grid state data



Future Needs

- Monitoring and control of distributed PV generation
- Distributed PV state estimation/forecasting
- Distribution system state estimation
- Ancillary services
- Active distribution switching and islanding

Project Innovation and Objective

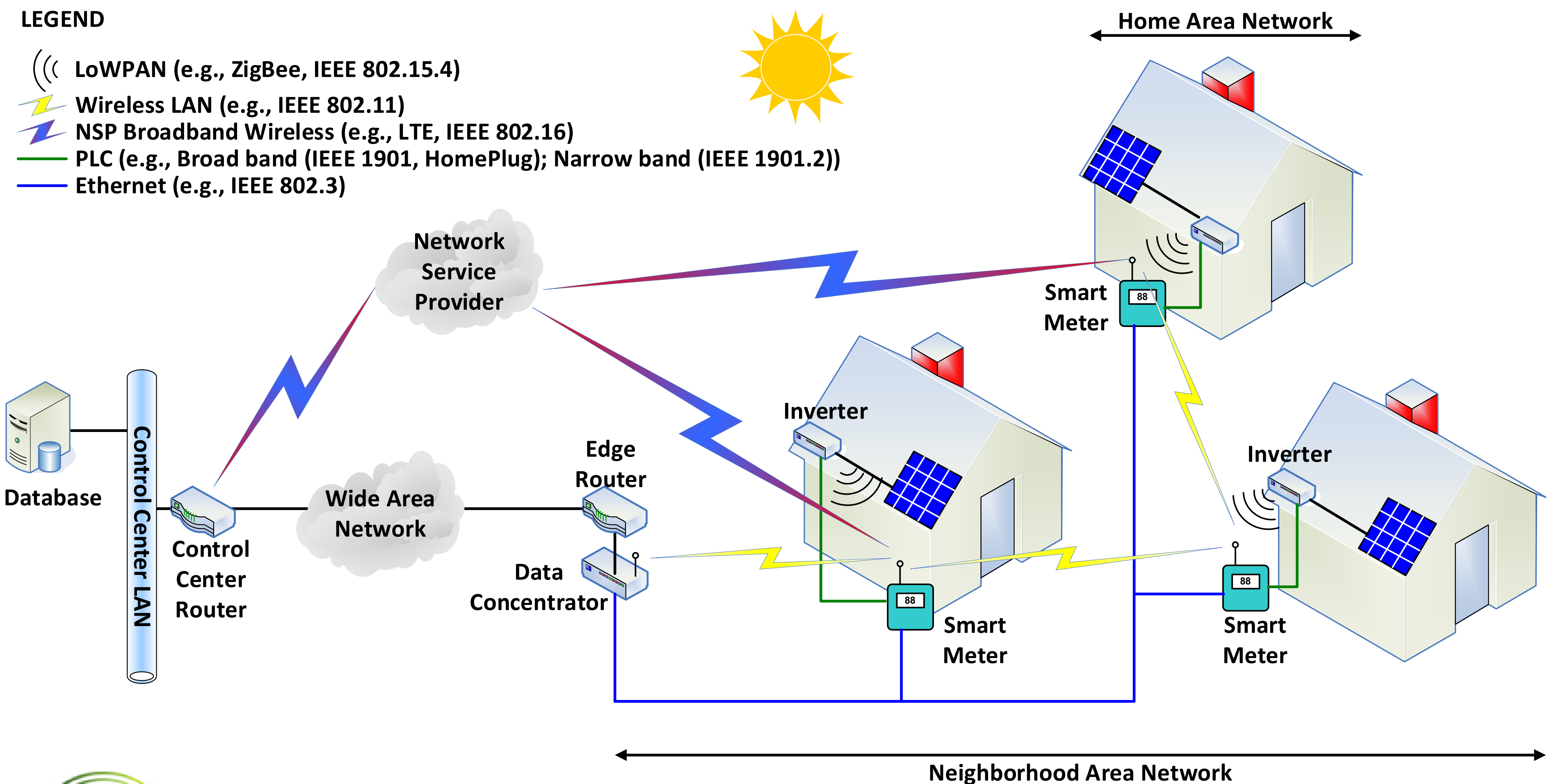


Innovation: To highly use the diverse communication infrastructure existed in the power system, we aim to develop the hybrid communication system at the least cost to coordinate distributed PV generation.

Objective: Communicate the state of the grid from the inverter to the system operator by full-scale, operational implementation of the opportunistic hybrid communication system:

- **Hybrid:** various communications pathways, e.g. LoWPAN, PLC, WiFi, WiMAX etc.
- **Opportunistic:** route messages through each of these systems based on recent data about latency and availability to ensure reliable message passing.

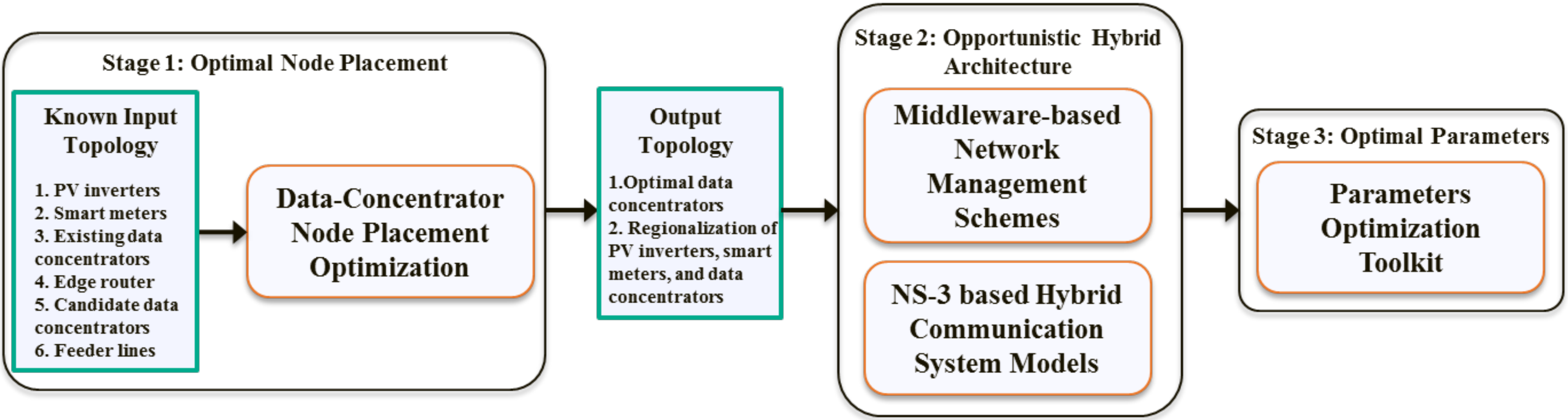
The Smart Grid Communication



Potential Use Cases and Applications

- Three design metrics: Latency, Throughput, and Packet Loss Rate for different hybrid communication architecture designs;
- Monitoring Functions: Distributed state estimation algorithms for distributed PV systems and distribution power systems;
- Control Functions: Distributed PV dispatch commands from DSO or TSO;
- Ancillary Services from utility point of view.

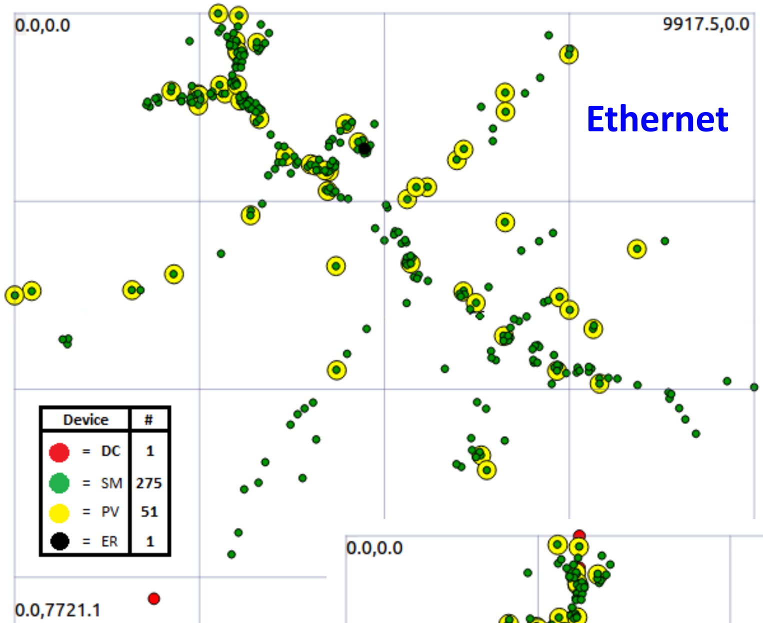
Hybrid Communication Design Stages

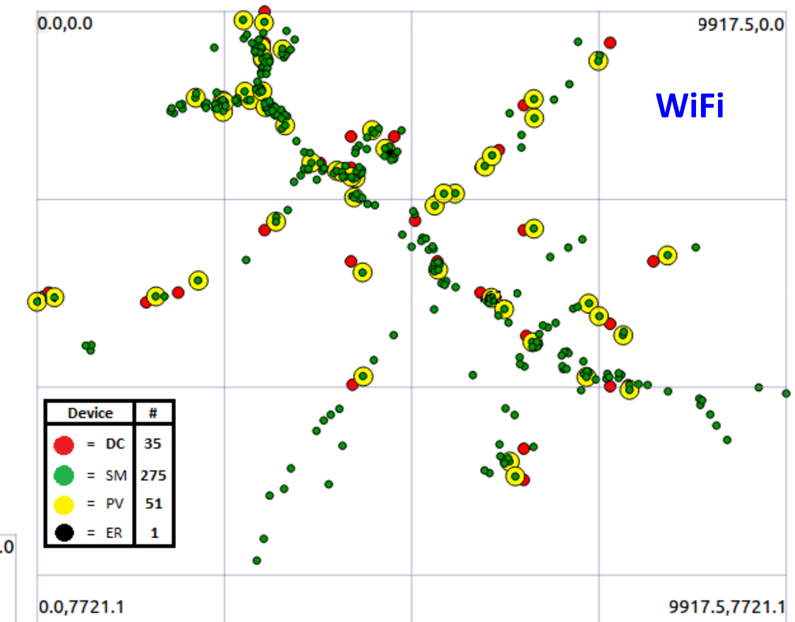


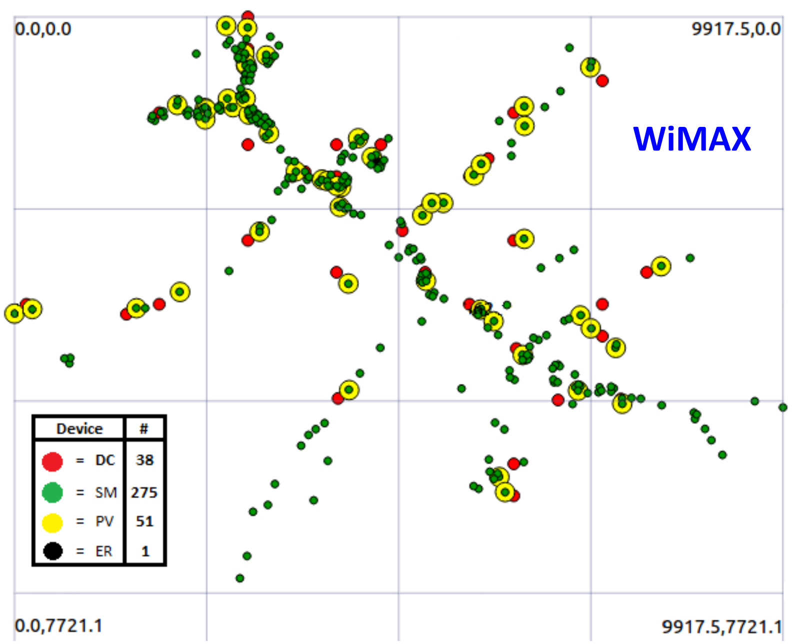
Reference Test Case A (RTC-A)

- Taxonomy feeder R2-25.00-1 from DOE's Modern Grid Initiative representing moderate urban environment
- System of 1080 nodes on a distribution feeder

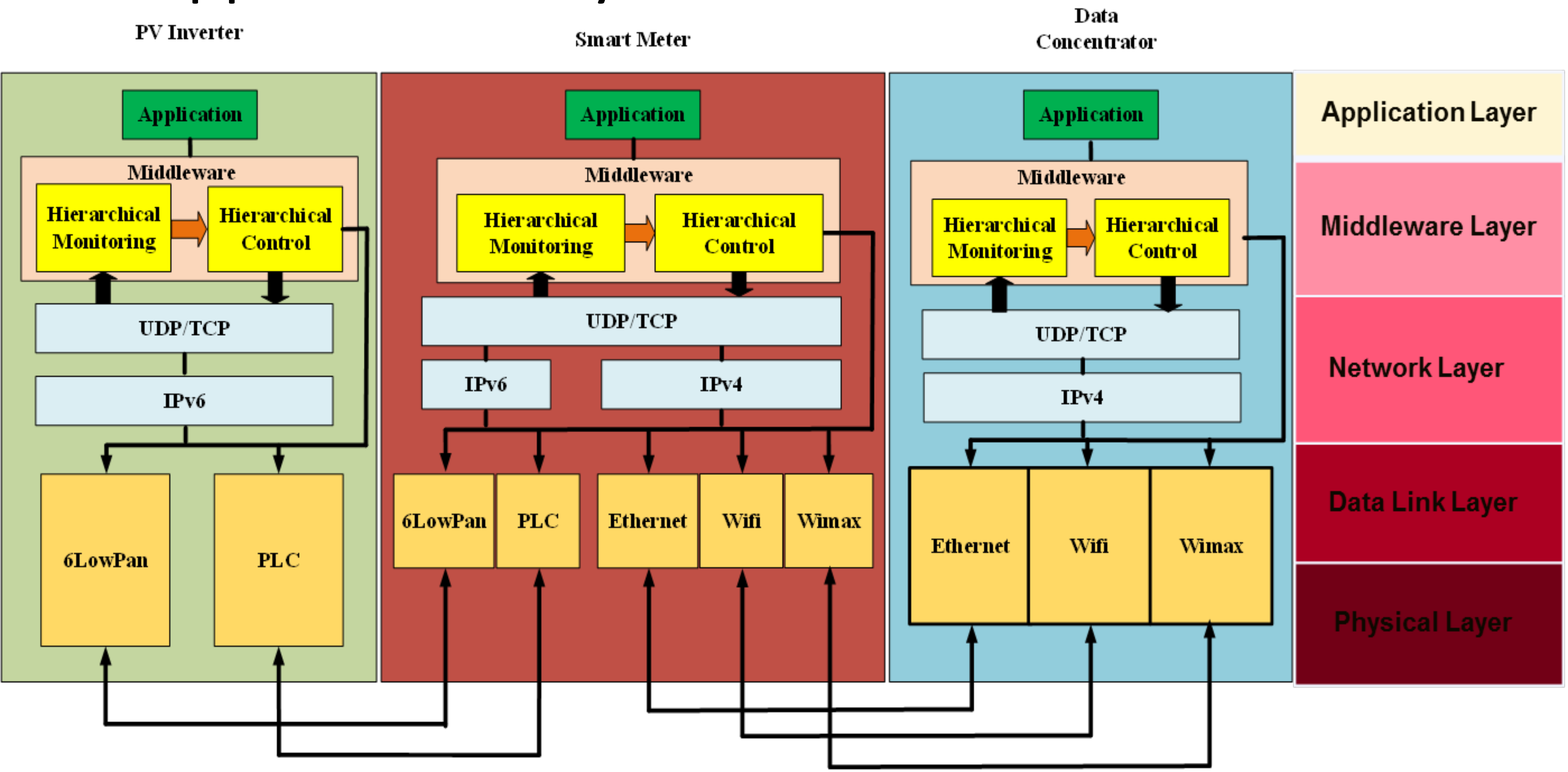
Data Concentrator Placement







Opportunistic Hybrid Communication Models

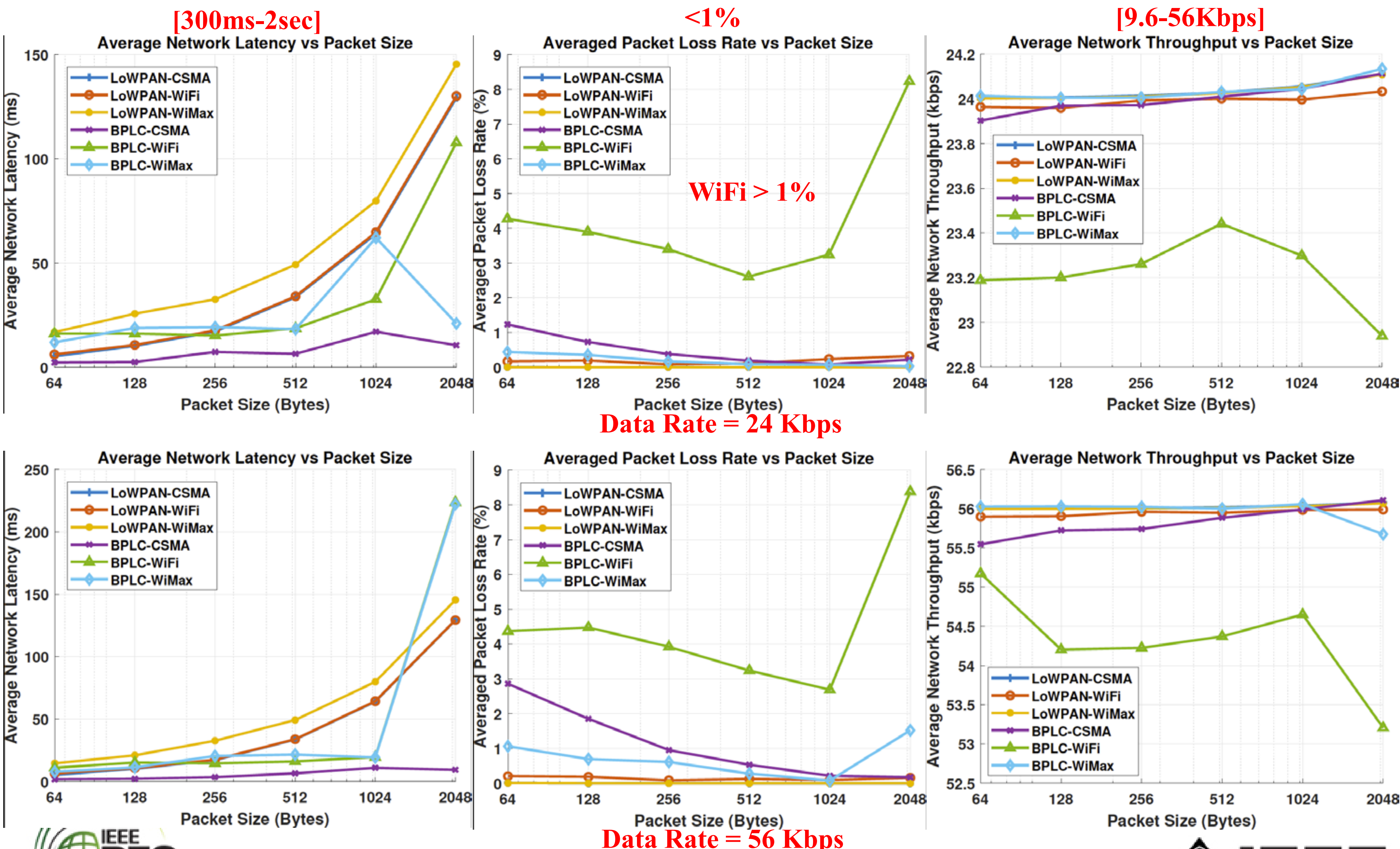


Home Area Network (HAN): **BPLC, NPLC, LoWPAN**

Neighborhood Area Network (NAN): **Ethernet, WiFi, WiMAX**

Total 9 hybrid designs

NS-3 Hybrid Communication Simulation Performance [1]



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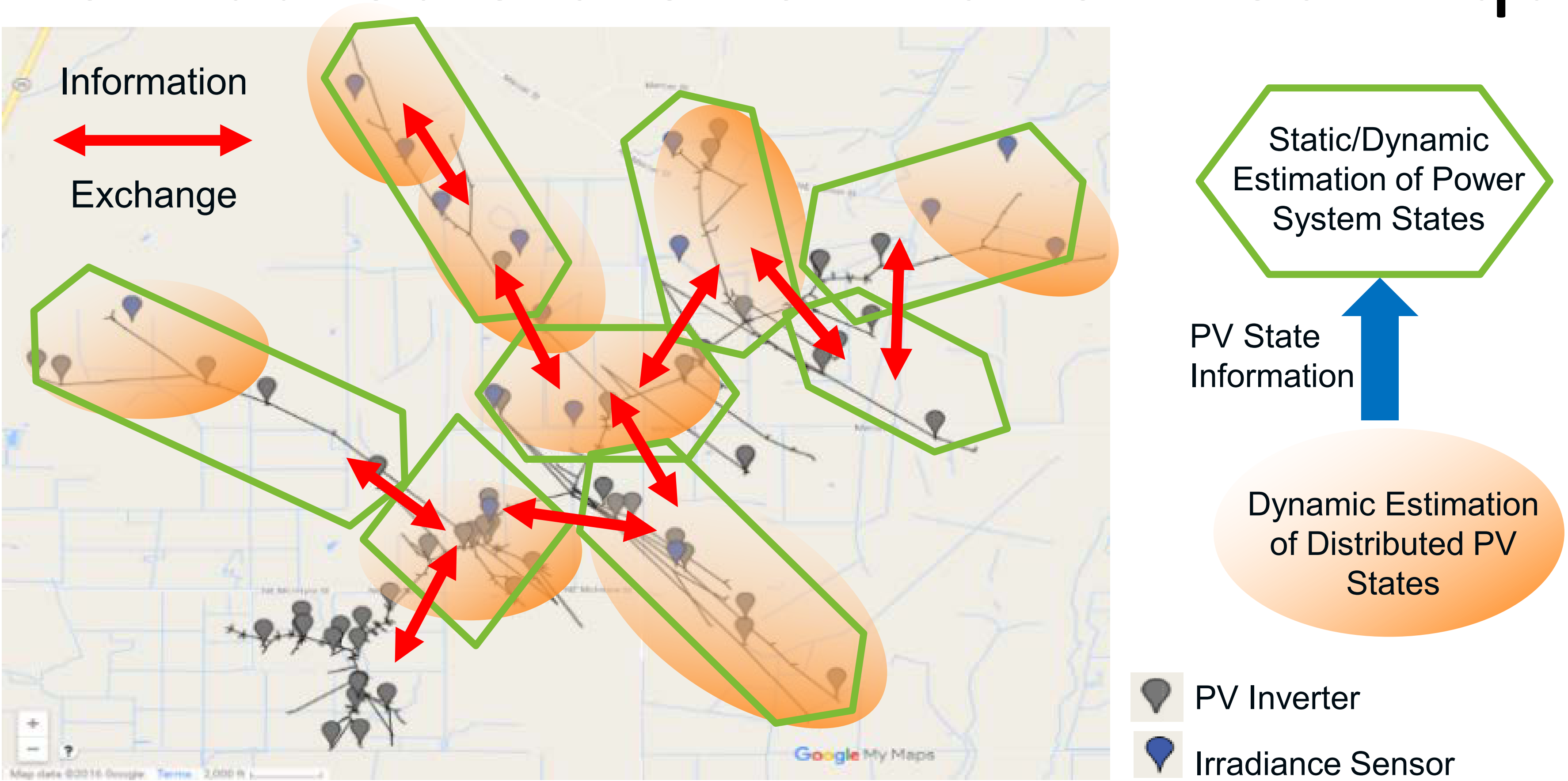
Optimal Performance and Parameters

Variables: Date rate and Packet size

TABLE IV: Optimal Parameter Results for Nine Hybrid Designs

Hybrid Type	Data Rate (Kbps)	Packet Size (Bytes)	Latency (ms)	Throughput (Kbps)	Packet Loss Rate (%))
LoWPAN-Ethernet	56	631	5.144	56.003	0
LoWPAN-WiFi	55.98	251	5.622	55.981	0.033
LoWPAN-WiMAX	55.85	795	11.75	55.849	0
BPLC-Ethernet	55.804	699	7.098	55.819	0
BPLC-WiFi	55.043	588	11.436	54.875	0.622
BPLC-WiMAX	55.551	70	7.102	55.559	0
NPLC-Ethernet	55.987	643	26.922	56.011	0.021
NPLC-WiFi	55.862	635	33.256	55.676	0.497
NPLC-WiMAX	56	756	41	56.032	0

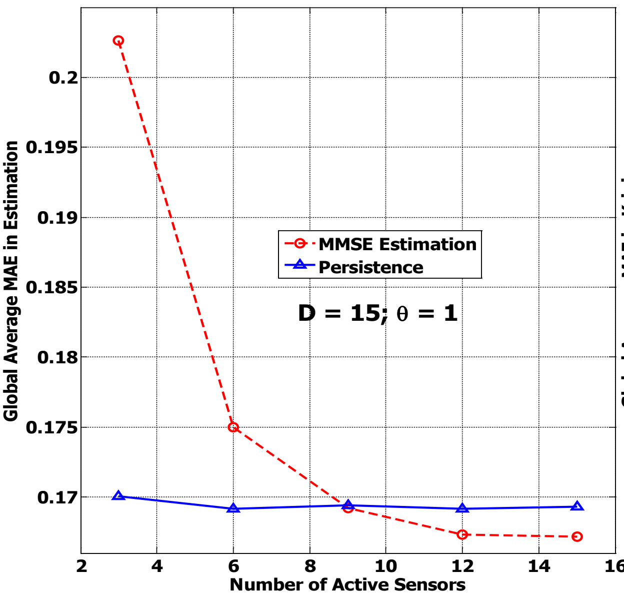
Distributed State Estimation Techniques

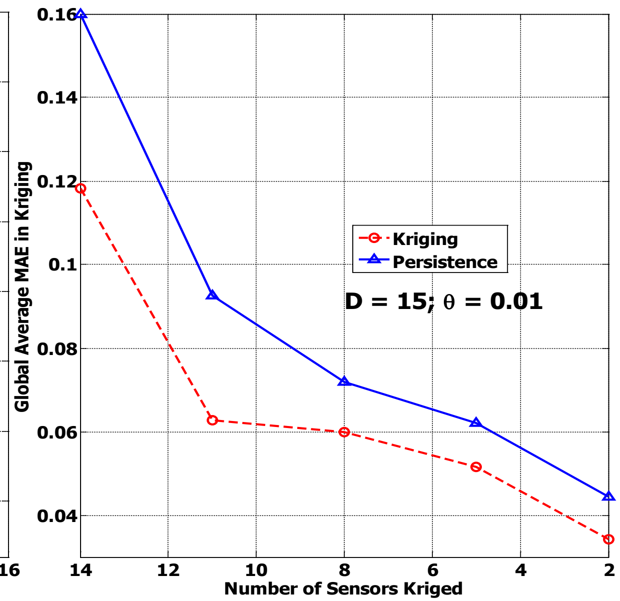


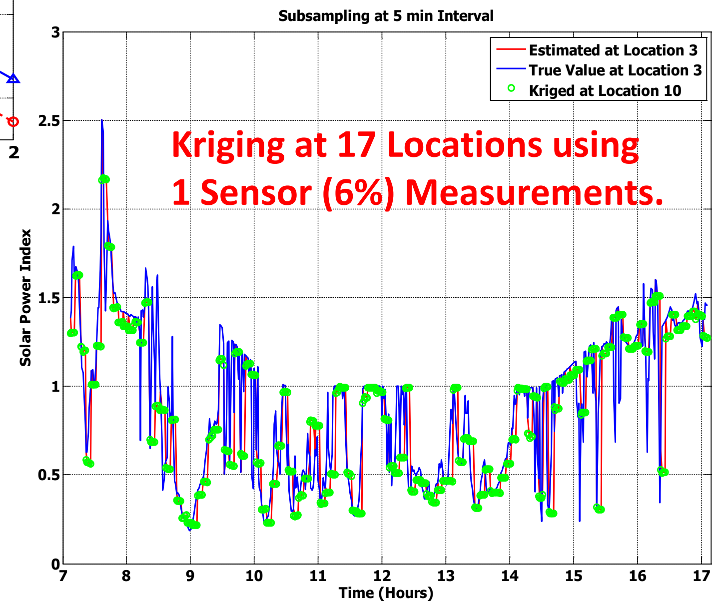
- Improve PV generation efficiency by using dynamic estimation of distributed PV states
- Enable monitoring and control of distribution PV generation using distribution state

Distributed PV System State Estimation

- **M**ulti **R**ate and **E**vent **DRI**ven **K**alman **K**riging (MREDRIKK) Filter [2].



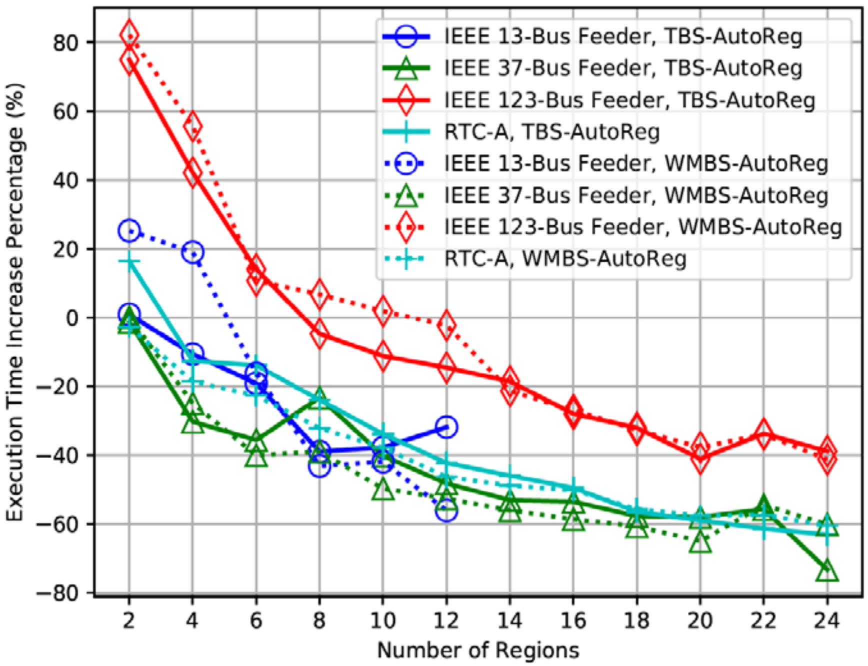




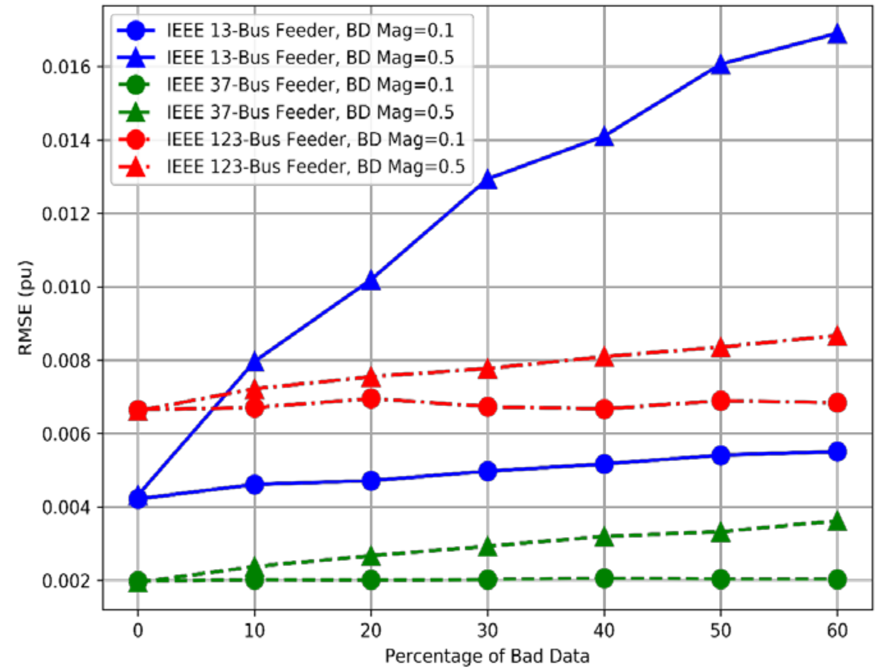
Estimation and Kriging Performs Better Than Persistence.

Distributed State Estimation for Power Distribution System

- Spectral clustering based automatic regionalization [3].
- **Di**stributed **L**adder **I**terative **S**tate **E**stimation (DiLISE) [4].

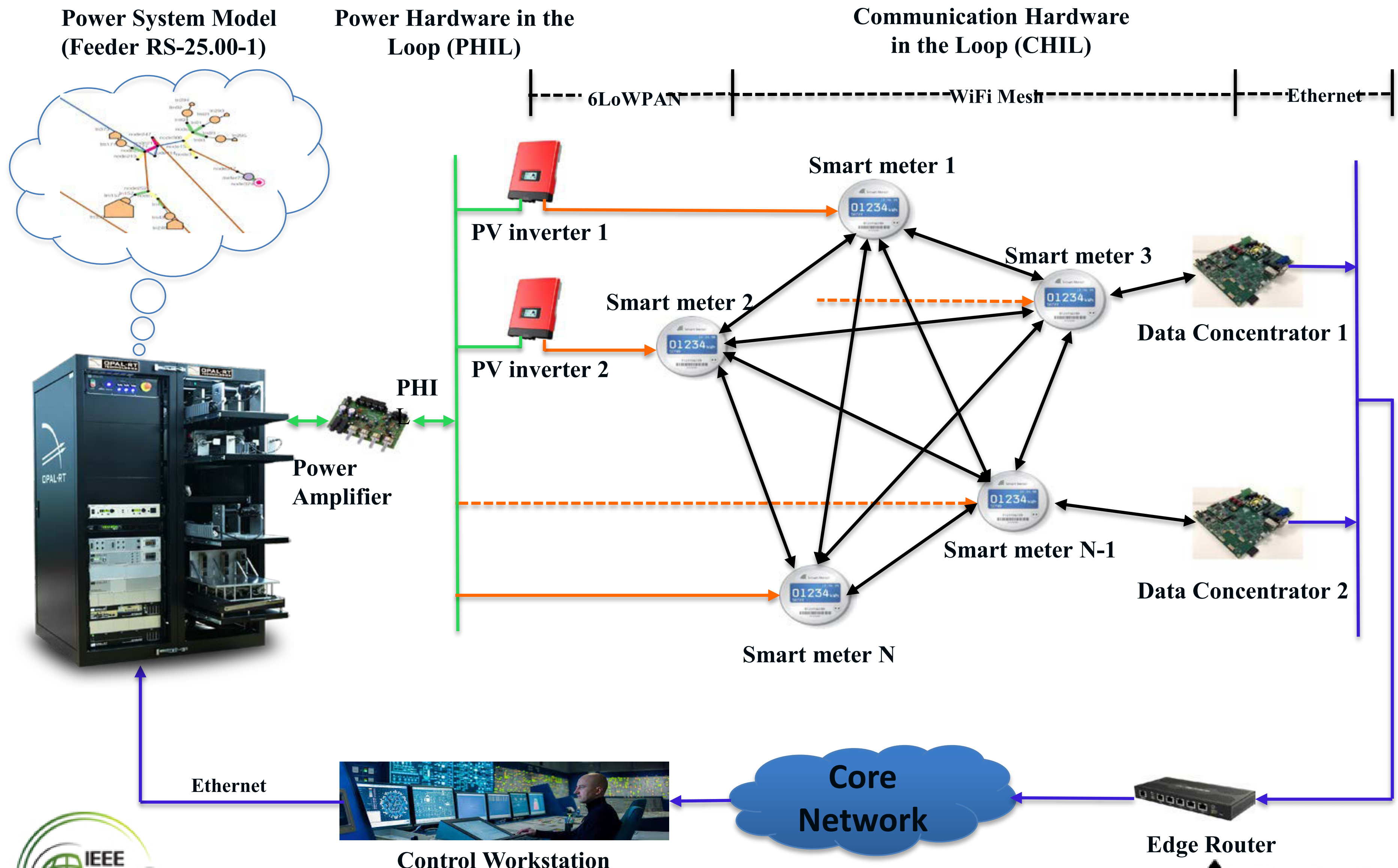


Performance of DiLISE for Different Test Cases



Impact of Bad Data on DiLISE Algorithm

Communication and Power HIL Test



In Progress…

- Integration of NS-3 simulation testbed with communication and power hardware-in-the-loop (HIL) testbed.

- Integration of distributed state estimation algorithms for power distribution system and distributed PV systems.

Reference

[1] Zhang et al., "Hybrid Communication Architectures for Distributed Smart Grid Applications", *1st revision submitted to MDPI Energies*.

[2] Alam et al., "Multi-Rate and Event-DRIven Kalman Kriging Filter for Distributed PV System State Estimation," *1st revision submitted to IEEE Trans. Smart Grid*.

[3] Wang et al., "Automatic Regionalization Algorithm for Distributed State Estimation in Power Systems", IEEE GlobalSIP 2016.

[4] Wang et al., "Distributed Ladder Iterative State Estimation and Automatic Regionalization for Distribution Systems", *1st revision submitted to IEEE Trans. Smart Grid*.

Thank You!!

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