A Service-Oriented Architecture for the Electric Distribution Grid

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Research Motivation

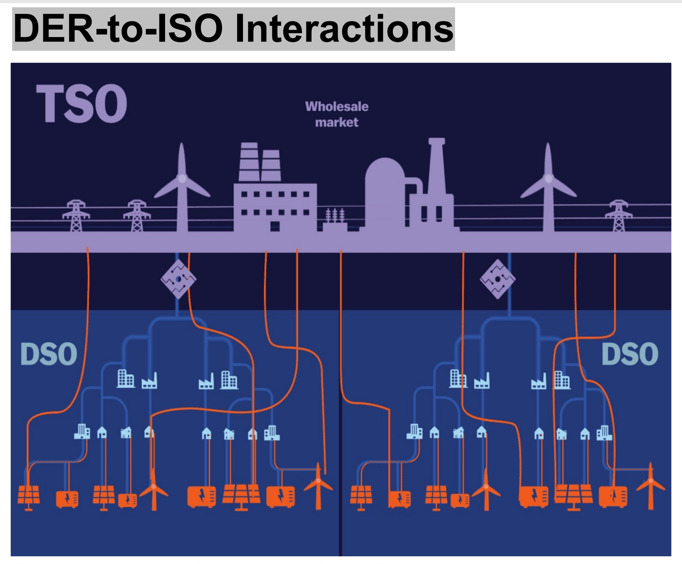
- Increasing number of Distributed Energy Resources (DERs) → large supply-demand imbalances lead to grid stability issues.
- Privately owned, so DER adoption is autonomous and disconnected with grid capabilities and capacity → extra burden is placed on the grid.
- Lack of appropriate compensation and incentives for capable DERs to participate in markets → inefficient use of assets.

Decline in overall grid stability and efficiency if the prevailing system architecture is unchanged!

Design a service-oriented architecture that permits private DERs to behave in accordance with the grid's overall interests <u>in addition</u> to their own.

Objective

DER-to-ISO Interactions



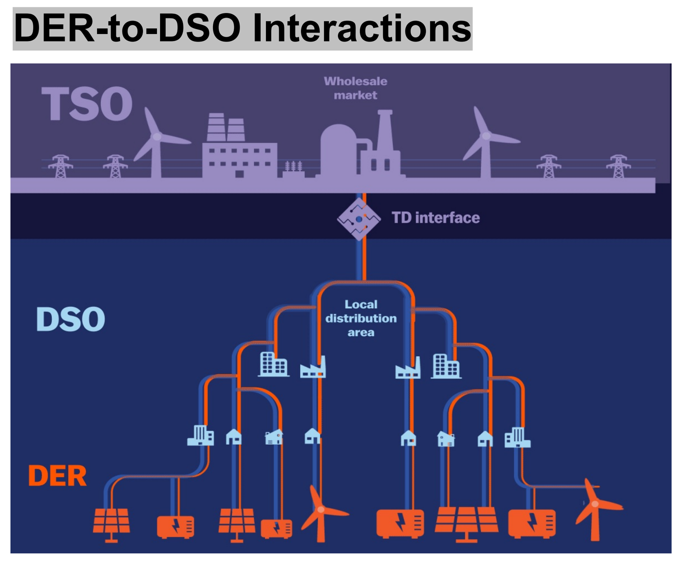
Source: Javier Zarracina, Vox Energy

State of the Art (Business as Usual)

- Scalability problems → unwieldy
- Circumvention leads to stability and visibility issues.
- Ad hoc and loose form makes it difficult to understand emergent behaviors that appear from the interactions of assets/agents.

Move towards a layered, well-defined, and self-optimizing electricity system

DER-to-DSO Interactions



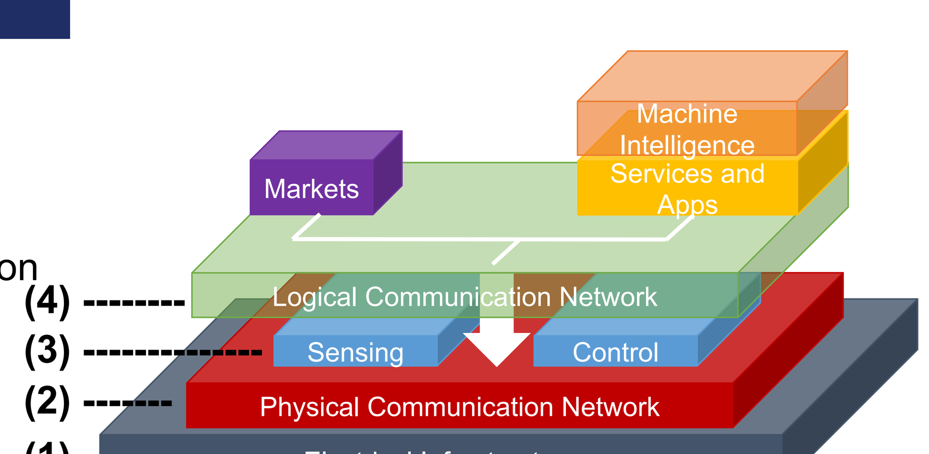
Source: Javier Zarracina, Vox Energy

Desired Coordination Framework

- Well-defined and layered structure, with optimal substructure → each layer is self-optimizing!
- Connectivity is easier to secure in the cyber domain.
- No circumvention of the layers. Hierarchical with well defined interfaces.

Possible components of our architecture:

- Spatial and temporal characterization of grid events.
- State estimation and forecasting.
- Autonomous decision-making.



Architecture will enhance level (4).

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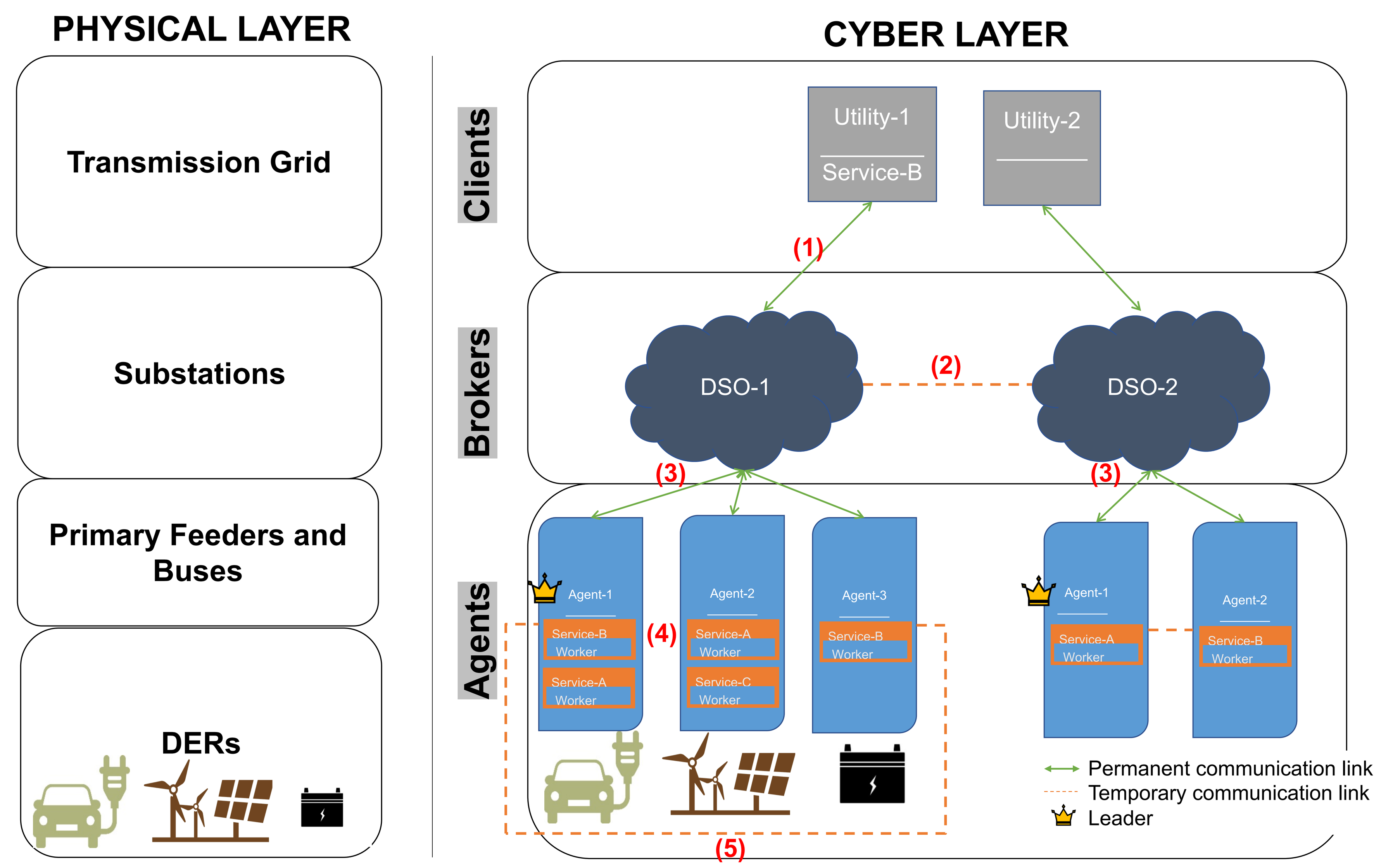
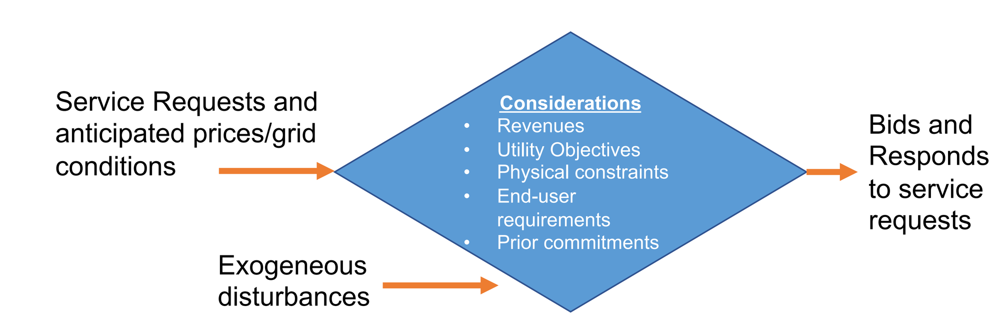
Proposed Architecture

- Service oriented:
  - Grid operators (i.e. utilities, independent system operators (ISOs), and aggregators) can select from a range* of services. Services are different tasks/goals which need to be met, and can include load shifting, coordinating retail electricity markets, microgrid islanding, basic diagnostics, etc. → service requests are deployed onto the agents (read: DERs) participating on the platform for completion.



1) *Utility-1's* request for **Service-B** is routed to *DSO-1*
2) *DSO-1* makes a temporary connection with *DSO-2* which can provide **Service-B** through *Agent-1* and *Agent-2*
3) *DSO-1* and *DSO-2* forwards *Utility-1's* request to agents whose workers can fulfill said service, along with the network address to other peers who can provide said service (*Agent-3*) and designates one of them to be the leader *(Agent-1* in both *DSO-1* and *DSO-2)*
4) *Agent-1's Service-B's* worker creates a peer-port socket to connect to its peers and form a group
5) Agents within the group work together to achieve *Utility-1's* request, result is collated by *Agent-1* and propagated to *DSO-1*

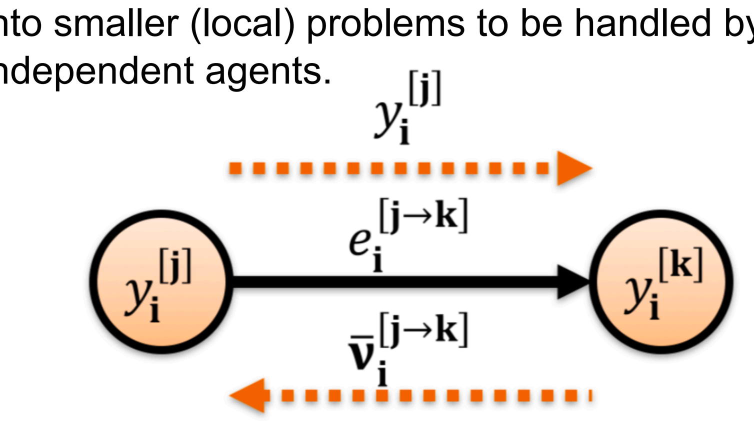
General Distributed Agent (DER) Decision Making



Example of Distributed Optimization: PAC Enabling Distributed Algorithms . . .

Proximal Atomic Coordination (PAC): Distributed optimization algorithm that makes use of the computational resources of different agents on the platform.

Key idea: Break down global problem (objective) into smaller (local) problems to be handled by independent agents.



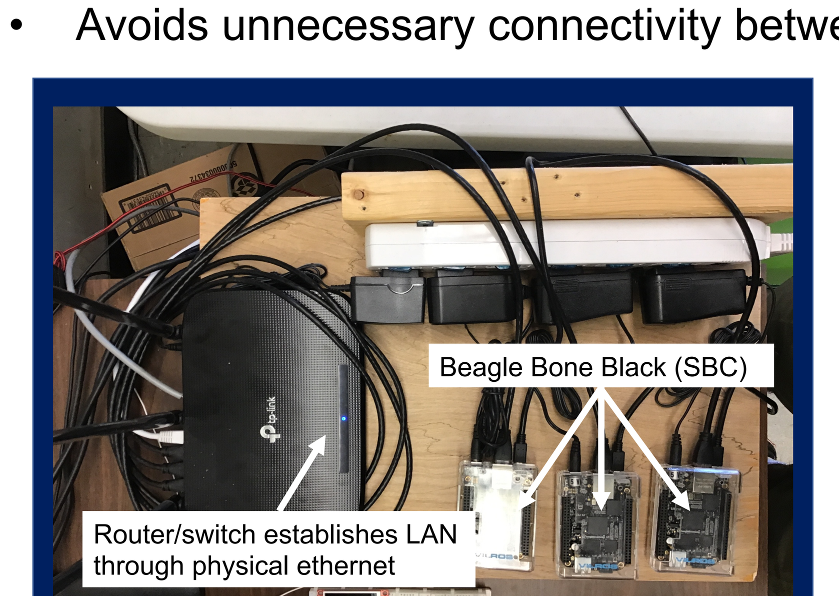
Source: MIT AACLAB

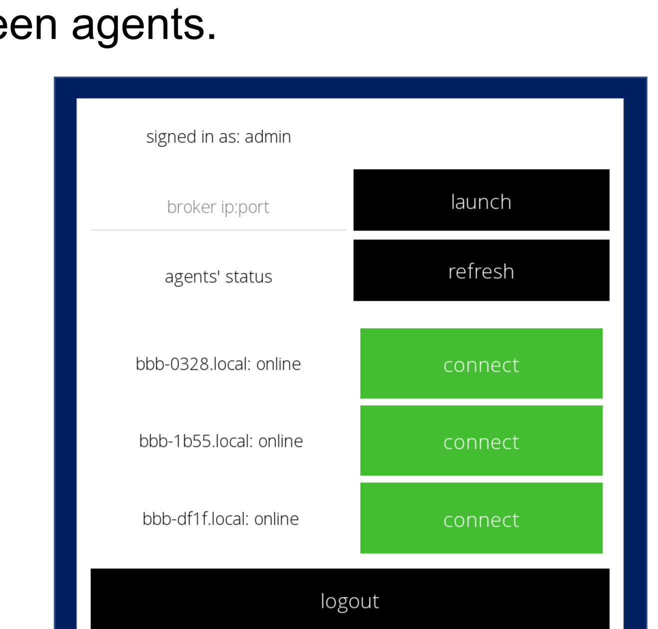
***Current Service Catalog**

- *Echo:* utility broadcasts message "a" and receives "a" back from the participating agents.
- *Sum to target scalar value*: utility has some target number t, agents have values v and work together such that $\sum v = t$. In the context of an electric grid, t might refer to the power imbalance that the utility would like the agents to cover.
- *Federated learning*: agents train a machine-learning model via message passing of gradient updates, and without sharing private data. This service serves as a generic template for distributed optimization algorithms, i.e. PAC.

Core Features

- Service API – developers can write services to be dispatched onto agents onboard the platform.
- Leverages distributed intelligence and resources of agents present in the platform.
- Basic task decomposition and leader election for asymmetric tasks.
- Broker detects and expels inactive agents.
- Avoids unnecessary connectivity between agents.





Left: Testbed, **Right**: GUI (Debugging mode) allows agents to be actuated remotely.

Conclusion

Coordinated control of agents could plausibly and significantly improve the resiliency of electric grids and maximize the value of existing assets.

Future Directions

- Improve robustness, security, and add services.
- Bake in the appropriate financial compensation and recording mechanisms.
- Perform agent drop-out tests, implement safeguards against malicious agents.
- Design metrics to gauge the network's health and "usefulness" to utilities.

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