DISTRIBUTED Energy Management

Verteiltes Energiemanagement mit LTE

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Motivation

Why Smart Grid?

Renewable Energy Sources

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Energy Fluctuations

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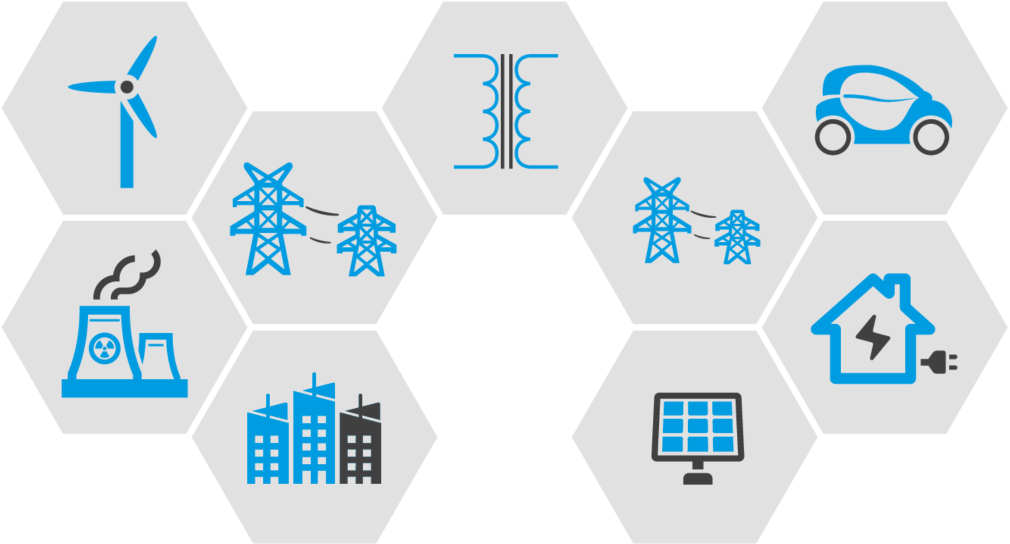
Distributed Energy Management

←

Distributed Prosumers



Requirements for Communication

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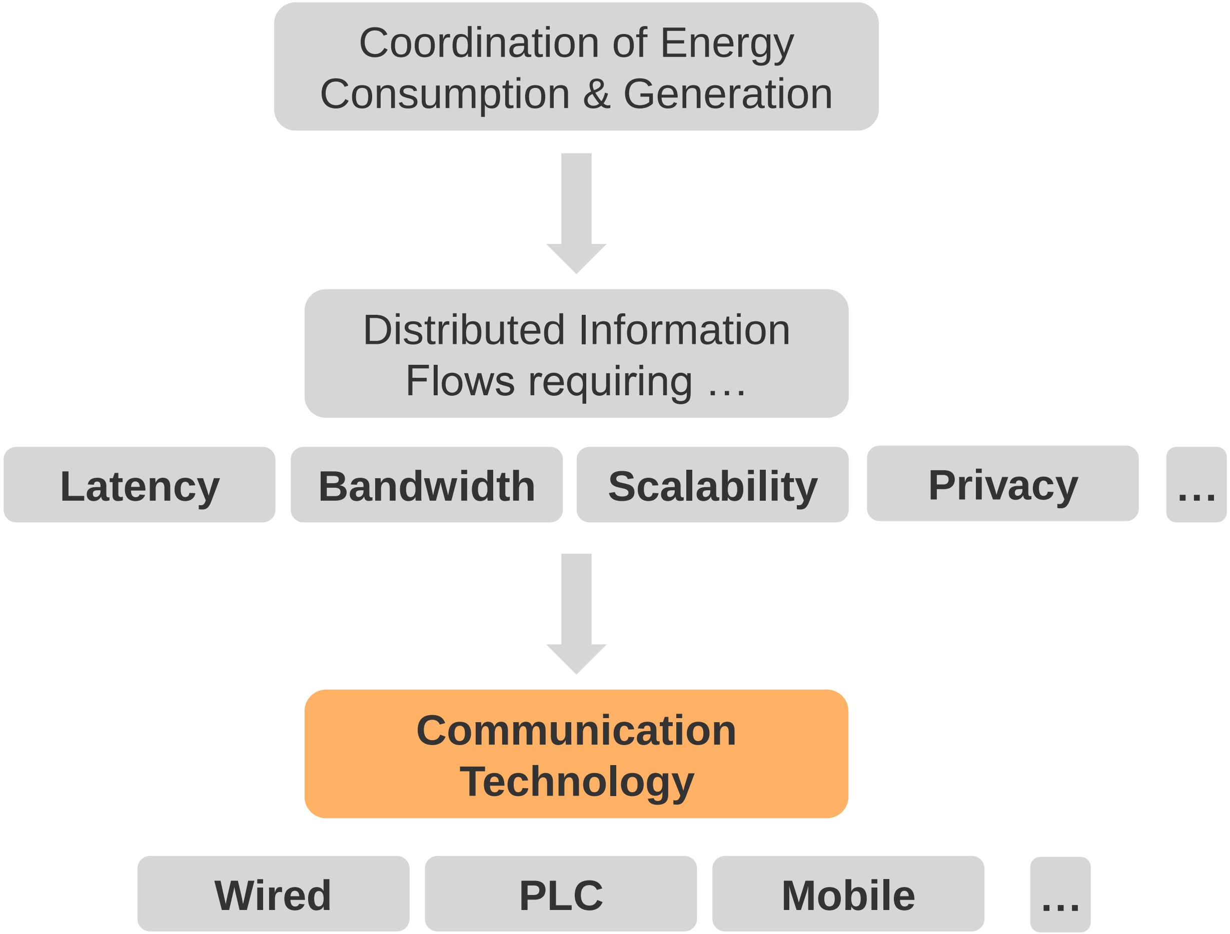

Distributed Energy Management (DEM)

State of the Art: DEM Algorithms

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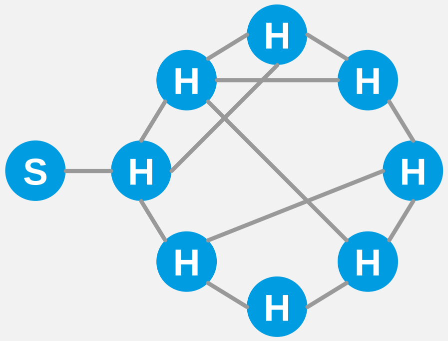
COHDA

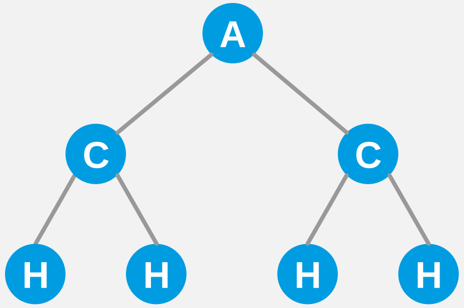
- Server publishes global goal
- Households maintain knowledge base
- If a better configuration is found, information is published to neighbours



Hinrichs, C., Lehnhoff, S., Sonnenschein, M.: COHDA: A Combinatorial Optimization Heuristic for Distributed Agents. In: Agents and Artificial Intelligence, no. 449 in Communications in Computer and Information Science, pp. 23-39. Springer Berlin Heidelberg (2013)

PowerMatcher

- Households create bids for devices
- Concentrators aggregate bids
- Auctioneer calculates price and publishes it
- Households set their consumption

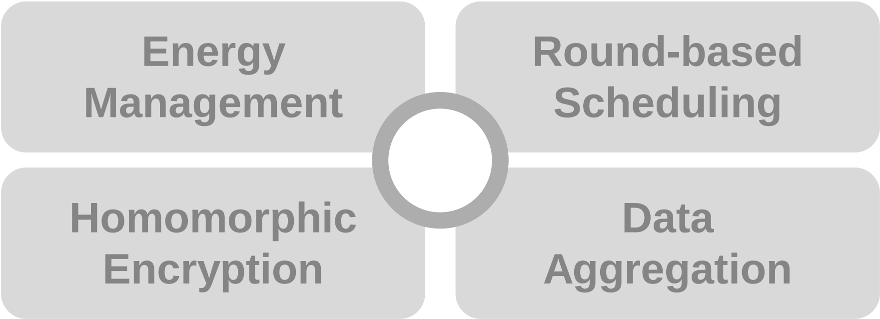


Kok, J.K.,Warmer, C.J., Kamphuis, I.G.: PowerMatcher: Multiagent Control in the Electricity Infrastructure. In: Proceedings of the Fourth International Joint Conference on Autonomous Agents and Multiagent Systems, AAMAS'05, pp. 75-82. ACM (2005)

Problem: No Privacy!

PrivADE

Privacy-Preserving **A**lorithm for **D**istributed **E**nergy Management



PrivADE

- Load shaping / peak clipping
- Switchable devices
  - Heatpump / CHP
  - Gather **categories** of devices
  - Switch whole categories
- Adaptable devices
  - Battery Storage / EV
  - Gather adaption potential
  - Max-min fairness scheduling
  - **Round-based**

PrivADE: DEM

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Round

1 **Gather switchable categories and adaption potential**
households publish encrypted information

2 **Publish categories and parameters for scheduling**
households switch and adapt devices

3^+ **Max-min fairness scheduling continues until target reached**
households adapt devices

Homomorphic Data Aggregation

$$\mathsf{D}(\mathsf{E}(m_1) \cdot \mathsf{E}(m_2) \bmod n^2) = m_1 + m_2 \bmod n$$

PrivADE: Ring

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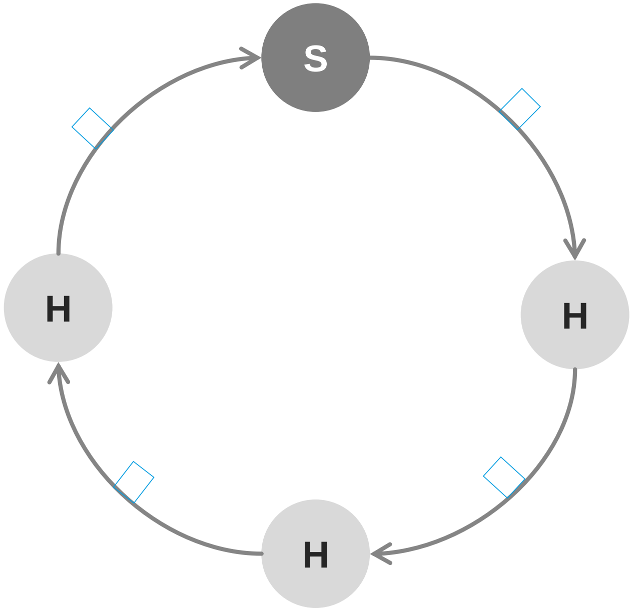
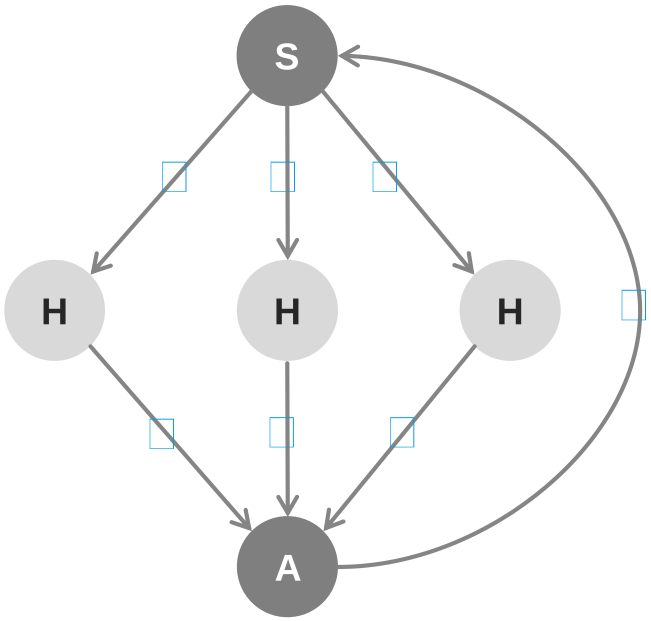


Ring Overlay Network

1. Server **starts** a round with **encrypted** data packet
2. Households **aggregate encrypted information** one after another
3. Server **decrypts aggregated information** after a round

PrivADE: Aggregator



Aggregator Overlay Network

1. Server **starts** a round with **parallel encrypted** data packets
2. Households **add encrypted information**
3. Aggregator **aggregates encrypted information**
4. Server **decrypts aggregated information** after a round

Co-simulation of Energy and Communication Networks

State of the Art

- Lévesque:
  - Simple voltage control
  - Simulates wireless communication with OMNeT++
  - Shortcomings
    - Only Electric Vehicles are managed, no heat devices, white goods or batteries
    - No comparison of Algorithms
    - No Scaling analysis

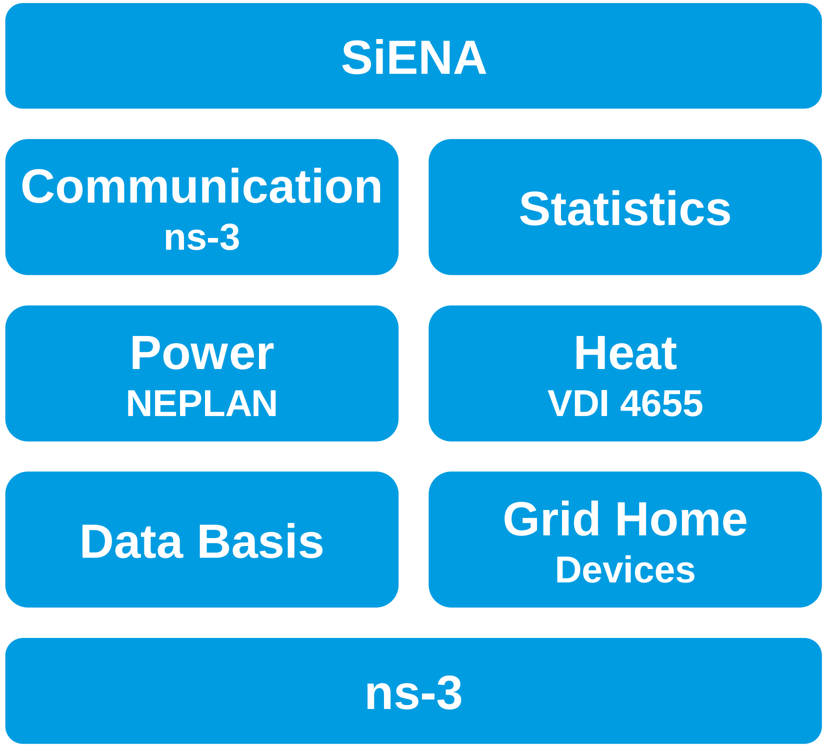
Martin Lévesque, et al. Communications and Power Distribution Network Co-simulation for Multidisciplinary Smart Grid Experimentations. In Proceedings of the 45th Annual Simulation Symposium, ANSS '12, Society for Computer Simulation International.

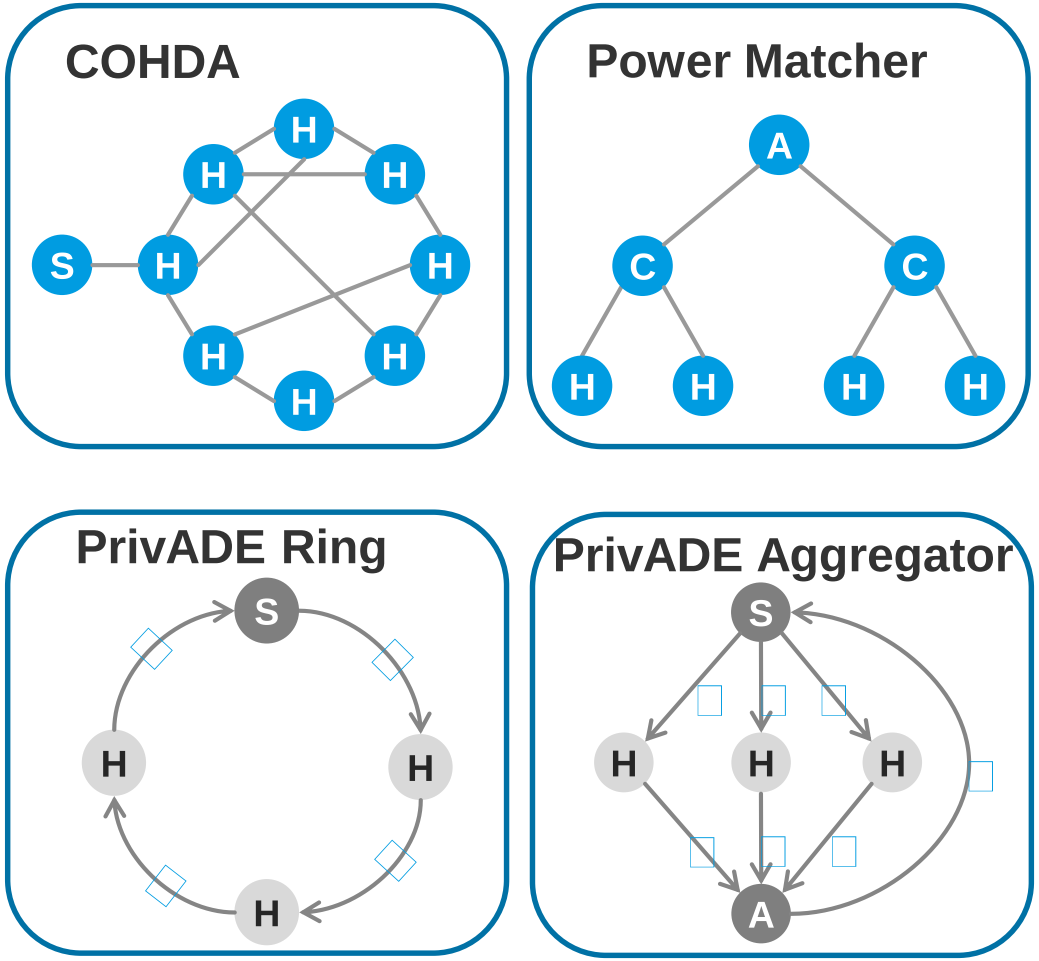
- Godfrey:
  - Voltage control algorithm
  - Simulates wireless communication with ns2
  - Shortcomings
    - Only Battery storages and Photovoltaic Systems simulated, no heat devices, no white goods
    - No comparison of Algorithms
    - No Scaling analysis

T. Godfrey, et al. Modeling Smart Grid Applications with Co-Simulation. In 2010 First IEEE International Conference on Smart Grid Communications (SmartGridComm)

=> Need for complete energy management co-simulation

Smart Grid Simulator SiENA

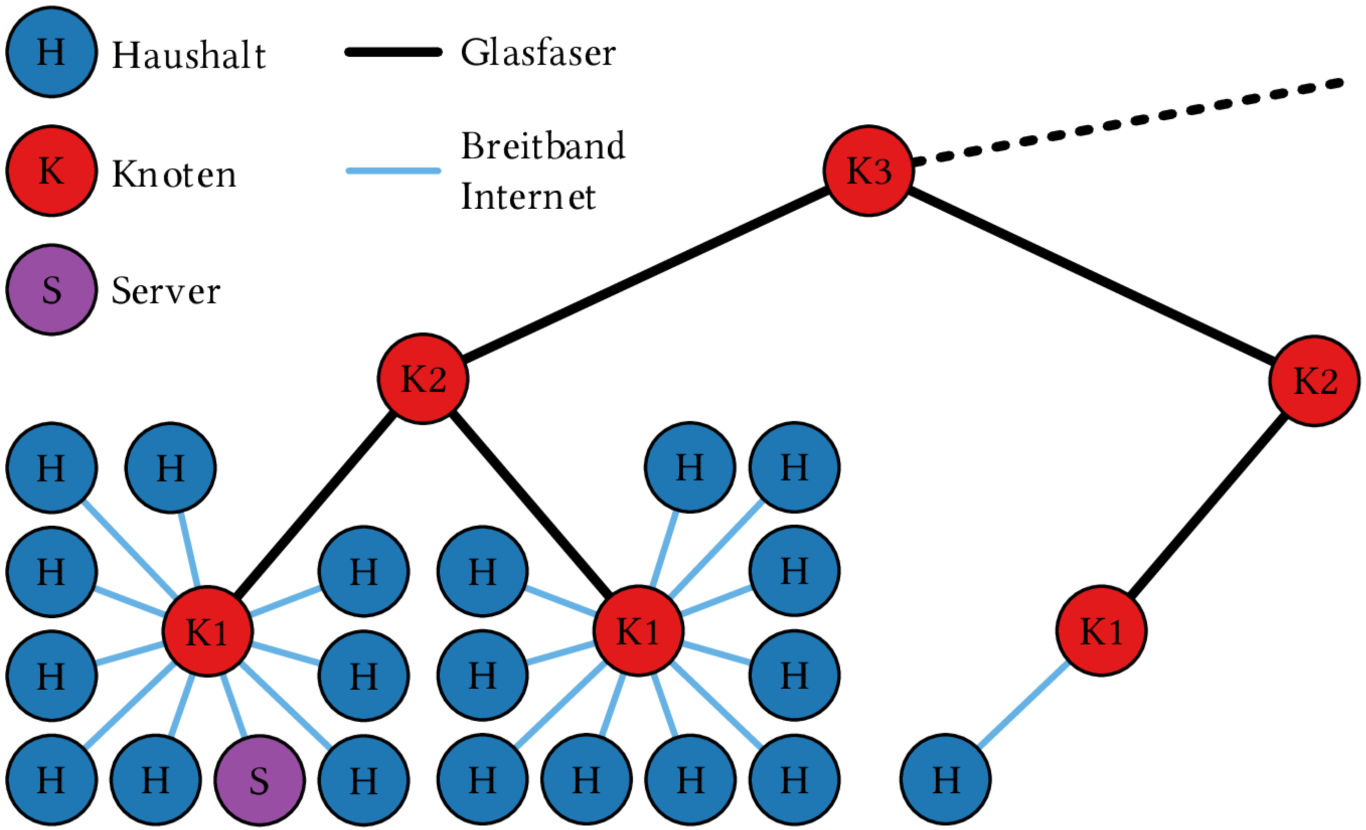




SiENA: Simulator for Energy Network Applications combining Power, Heat and Communication
VDE-Kongress 2016, Mannheim

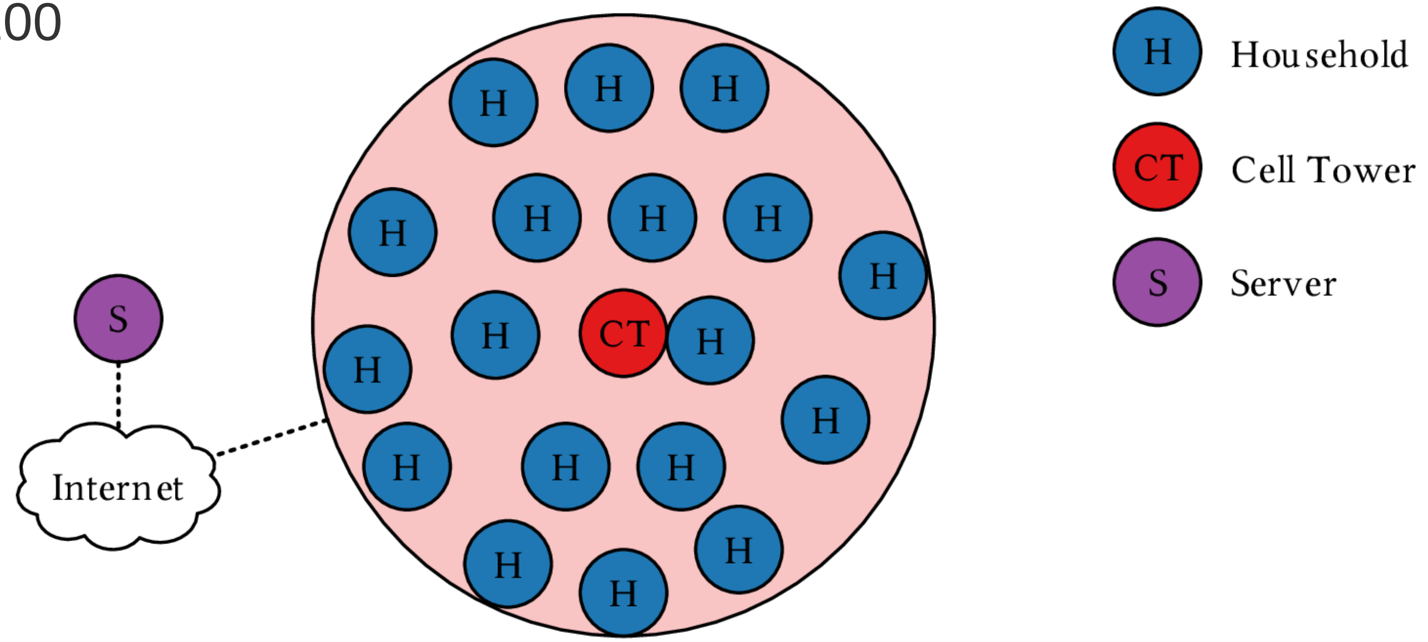
Com Net: Tree

- Wired broadband access
  (e.g. Internet Access via DSL)
- Households and servers at bottom layer
  - 5 Mbps
  - 20 ms latency
- Routers for additional hops
  - 1 Gbps
  - 2 ms latency



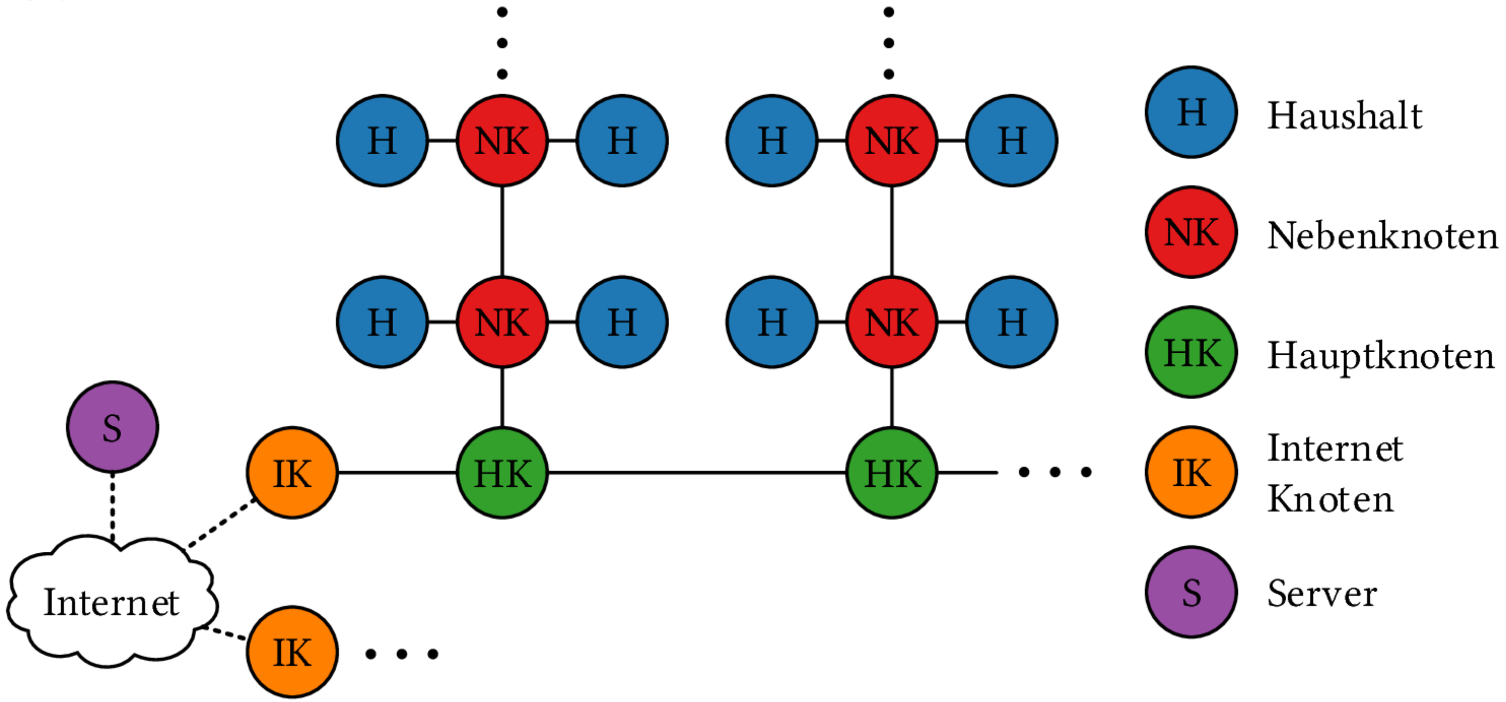
Com Net: LTE

- Cellular LTE Network
- Households and servers connected
  - LteEnbNetDevice::UlBandwidth: 25 Mbps
  - LteEnbNetDevice::DlBandwidth: 25 Mbps
  - LteEnbNetDevice::DlEarfcn: 100
  - LteEnbNetDevice::UlEarfcn: 18100
  - LteUePhy::TxPower: 10 dBm
  - LteEnbPhy::TxPower: 30 dBm



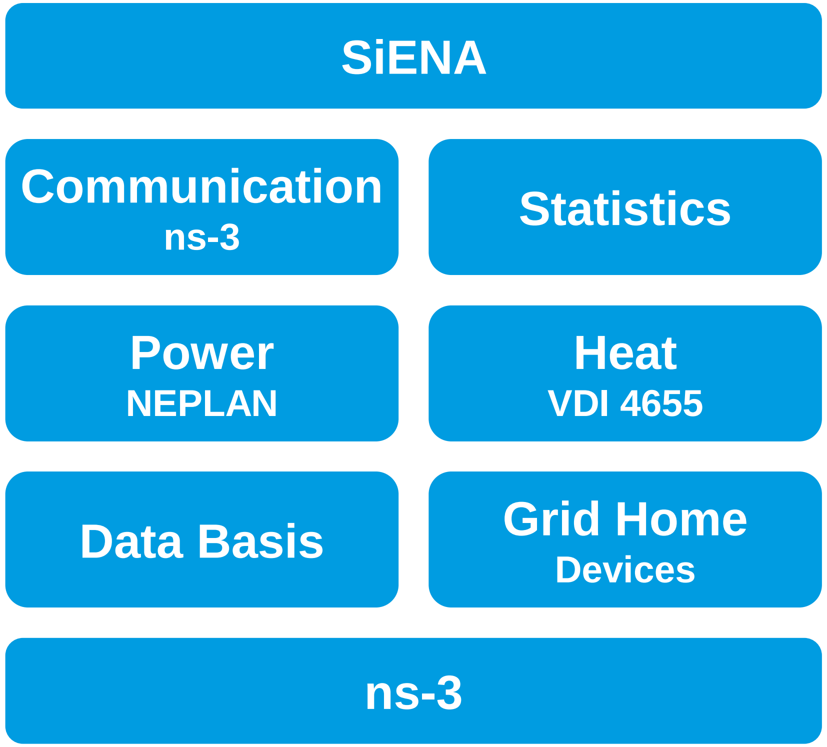
Com Net: PLC

- Powerline Communication
- PRIME
  - CENELEC-Band A (42 – 89 kHz)
  - OFDM, D8PSK, CSMA/CA
  - 128 kbps



Evaluation

Simulation Scenario



SiENA: Simulator for Energy Network Applications combining Power, Heat and Communication
VDE-Kongress 2016, Mannheim

Parameter	Value
Households	100
Connected Homes	All
Basic Appliances	All
Washing Machines	94
Dishwashers	67
Driers	39
PV	20
Batteries	30
Heat Pumps	20
µCHPs	28
Heating Rods	one for each HP and µCHP
Electric Vehicles (EVs)	29
Simulation Time	01/05/11 to 07/05/11

SiENA: Simulation Models

- Household
  - Single or multi-family
  - Living space (statistical data)
  - Residents depending on living space (statistical data)
  - Heat demand (VDI 4655, based on household and weather)
- Battery Storage (BS)
  - Full flexibility at all times
- Electric Vehicle (EV)
  - BS with occasional trips (duration, distance, fuel economy)
  - Adaptable, if charge > 90%
  - Can reduce charge rate or provide energy
- Photovoltaic System (PV)
  - Size distribution from 30000 deployed systems
  - Multi-year generation curves from 27 deployed systems

SiENA: Simulation Models

- Heat Pump (HP)
  - Hot water storage
  - Consumes power, generates heat
  - Switchable, if charge > 50%
  - Minimum runtime 15 min (to reduce wear)
  - Size depends on households parameters
- Micro Combined Heat and Power System (µCHP)
  - Hot water storage
  - Generates power and heat
  - Switchable, if charge > 50%
  - Minimum runtime 120 min (to reduce wear)
  - Size depends on households parameters
- Heating Rod
  - Supports HPs and µCHPs in critical situations

Evaluation: Criteria

1. Energy management quality
   - Privacy should not degrade energy management quality
   - Measured in load shaping and peak clipping quality
2. Communicational Cost
   - Use existing technologies in households
   - Measured in communication time and data volume
3. Privacy
   - No internal or external adversary can gain access to consumption traces or device states
   - Measured in k-anonymity

Evaluation: Energy Management

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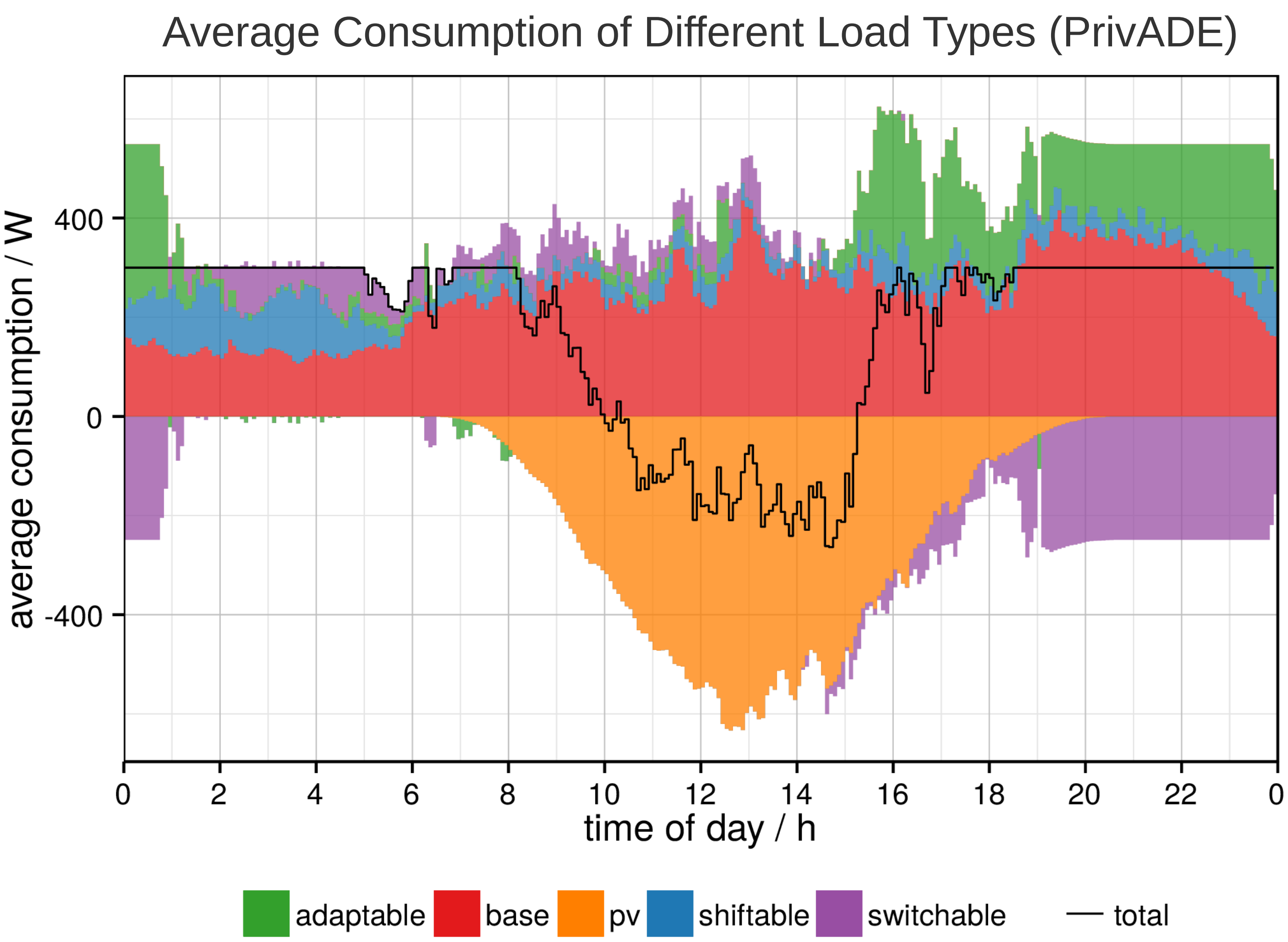
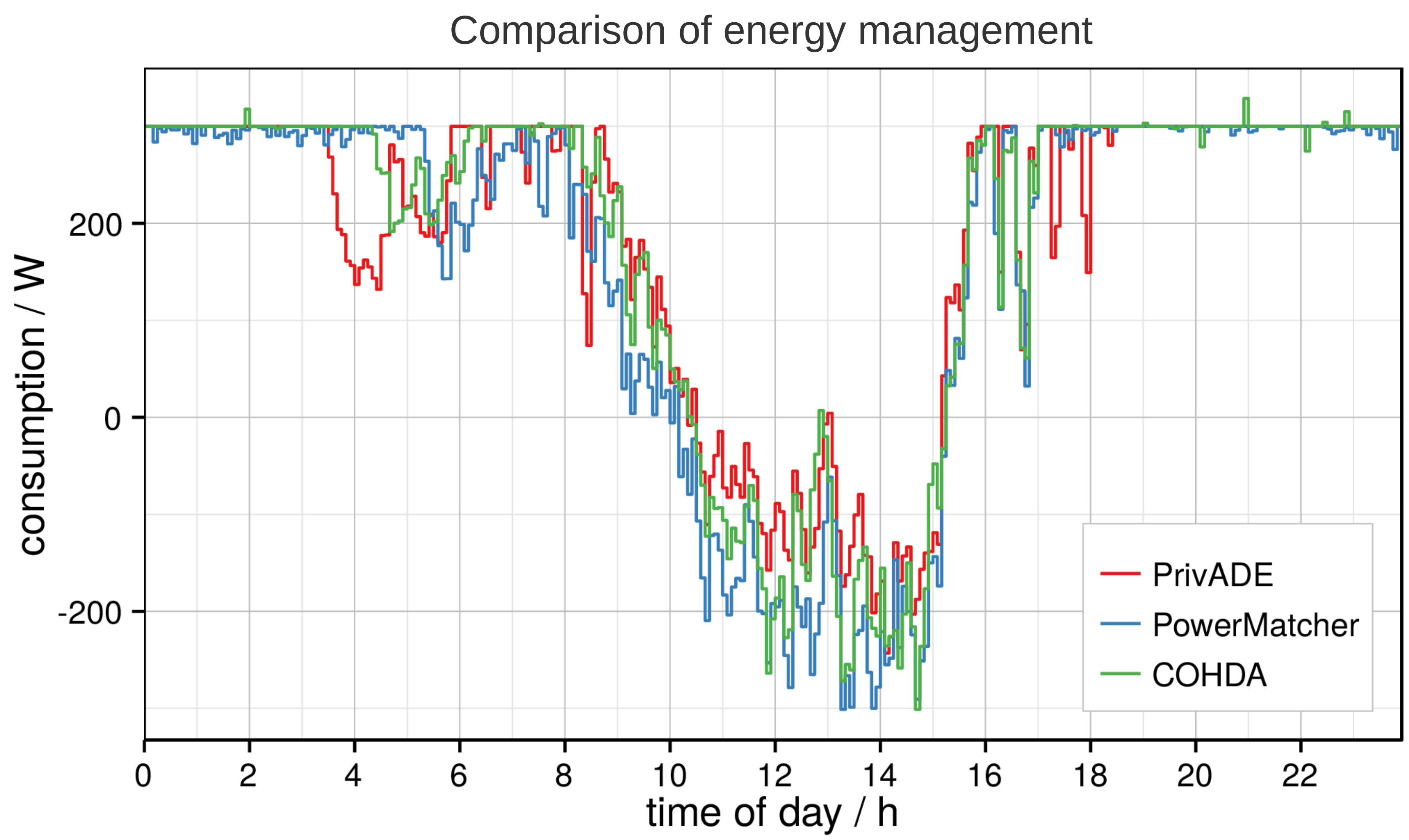


Evaluation: Energy Management Quality



Quality-functions for an uniform and comparable analysis of demand side management algorithms
Energieinformatik 2014, Zürich

Evaluation: Communicational Cost

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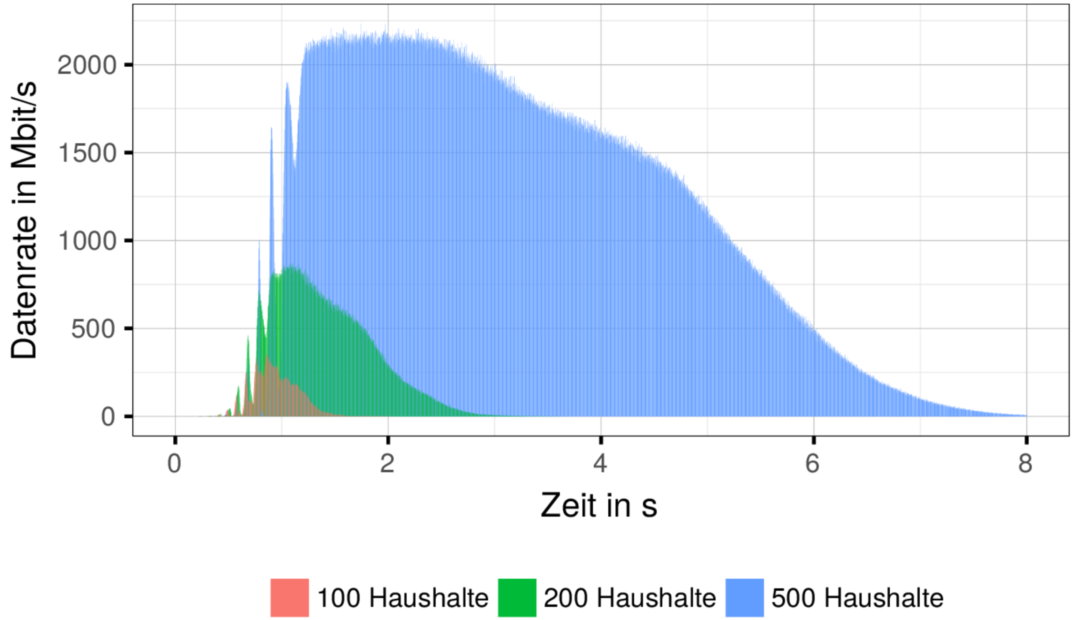
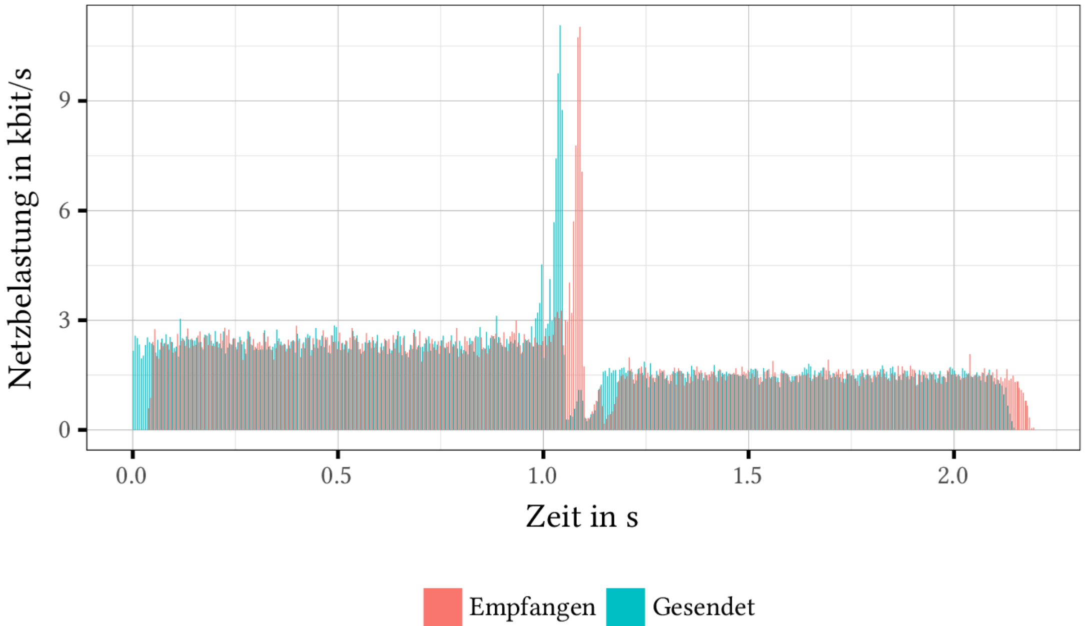
- COHDA
  - Parallel message flow
  - Large amount of messages
- PowerMatcher
  - Small message size
  - Static number of messages: $2 \cdot (|H| + |C|)$
- PrivADE Ring
  - Sequential message flow
  - Number of messages: $R \cdot (|H| + 1)$
- PrivADE Aggregator
  - Parallel message flow
  - Number of messages: $R \cdot (2 \cdot |H| + 1)$





Evaluation: Data Volume (100 households)

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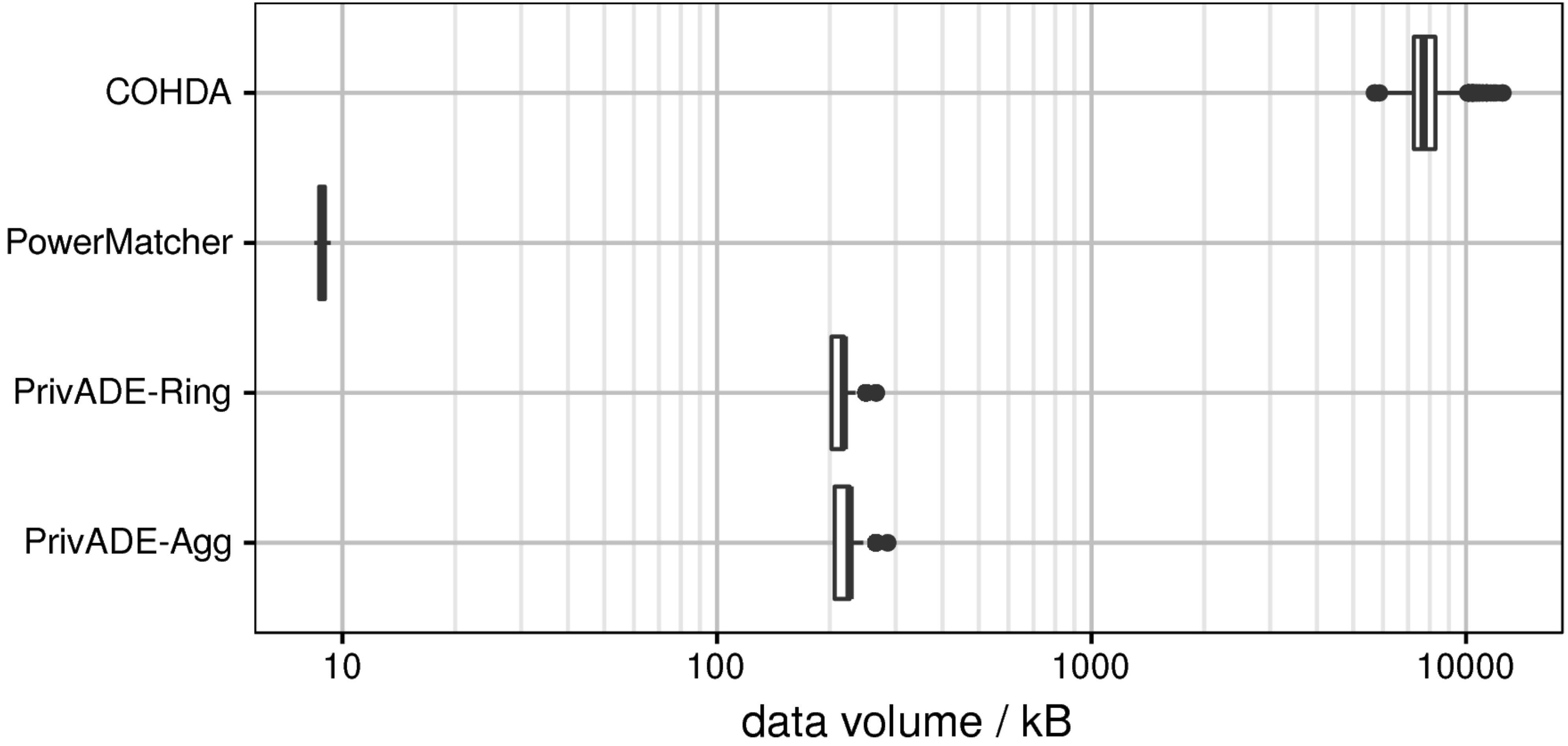
Requirements for data volume
per energy management interval



Evaluation: Convergence Time (Tree)

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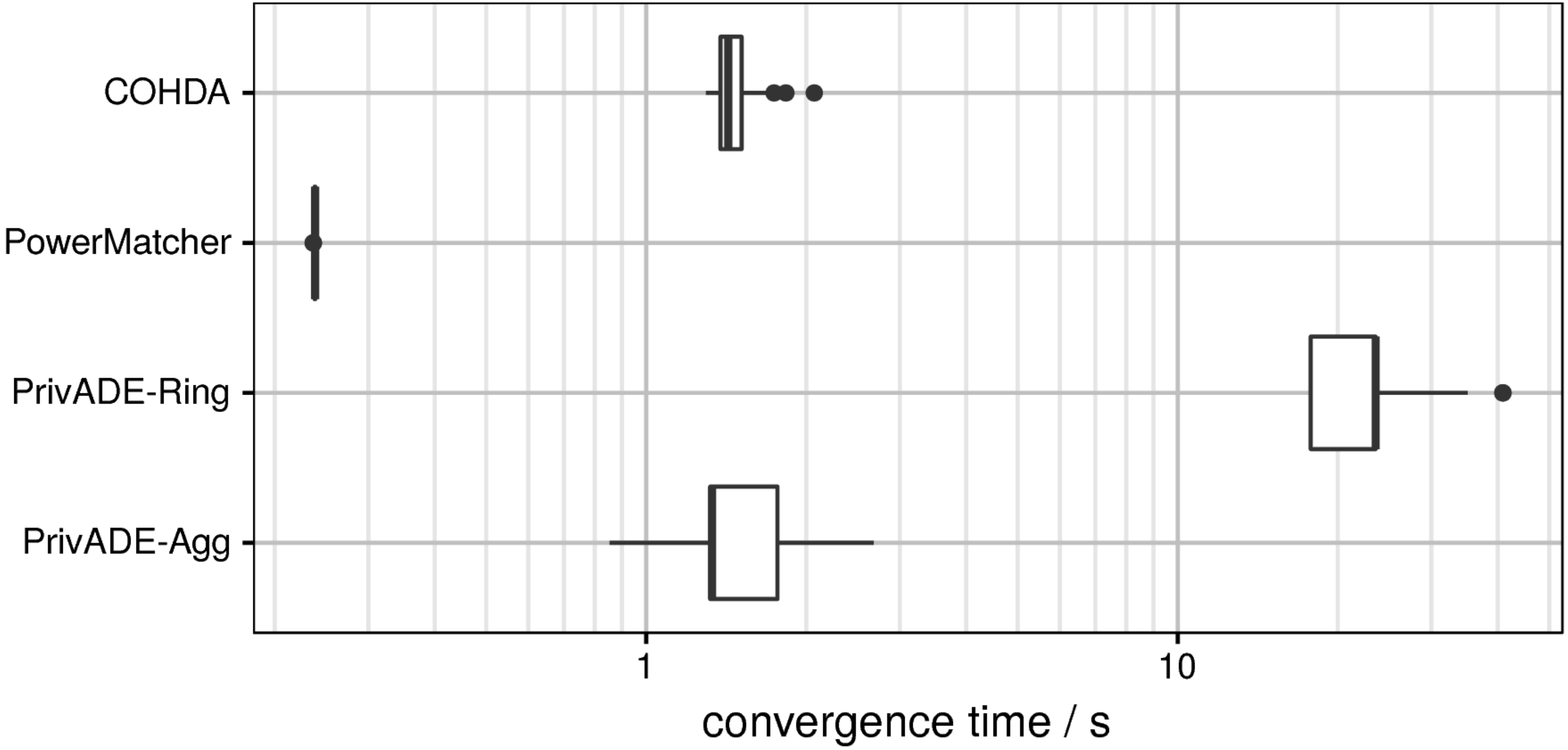
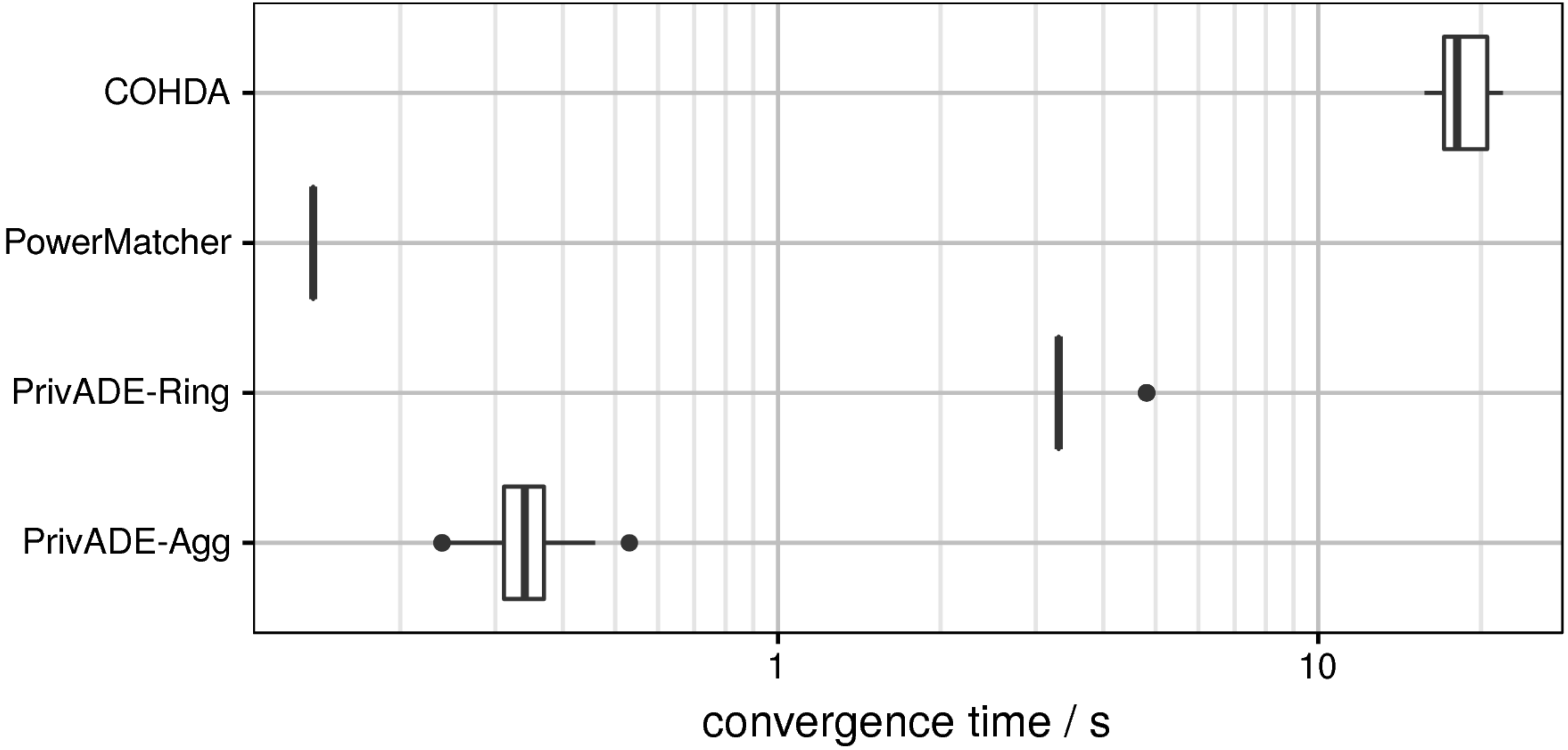
Wired Broadband Access
Required time until algorithm convergences
in an energy management interval



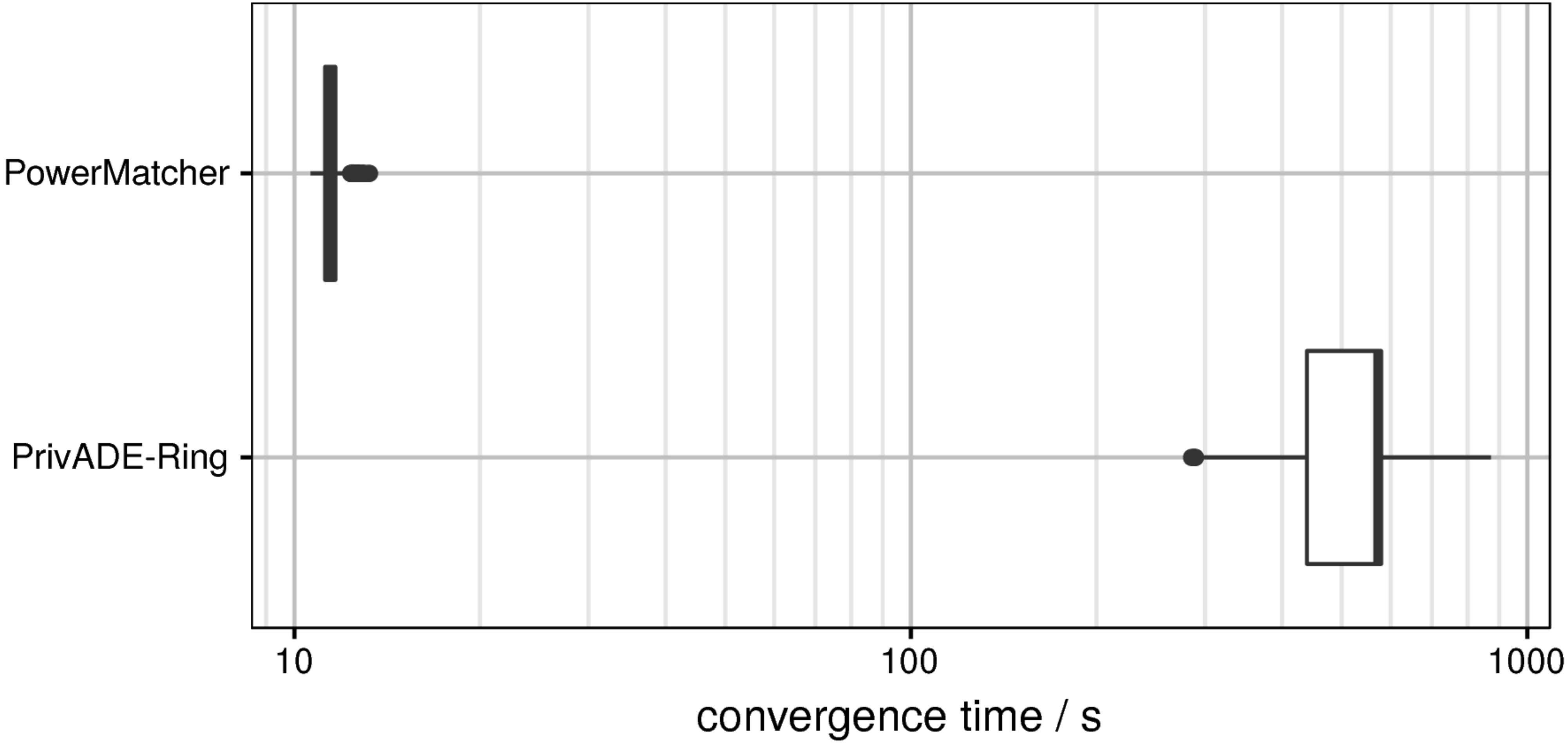
Evaluation: Convergence Time (LTE)

LTE
Required time until algorithm convergences
in an energy management interval



Evaluation: Convergence Time (PLC)

PLC
Required time until algorithm convergences
in an energy management interval



(COHDA and PrivADE Aggregator cannot run due to heavy data volume)

Evaluation: Scalability (Data)

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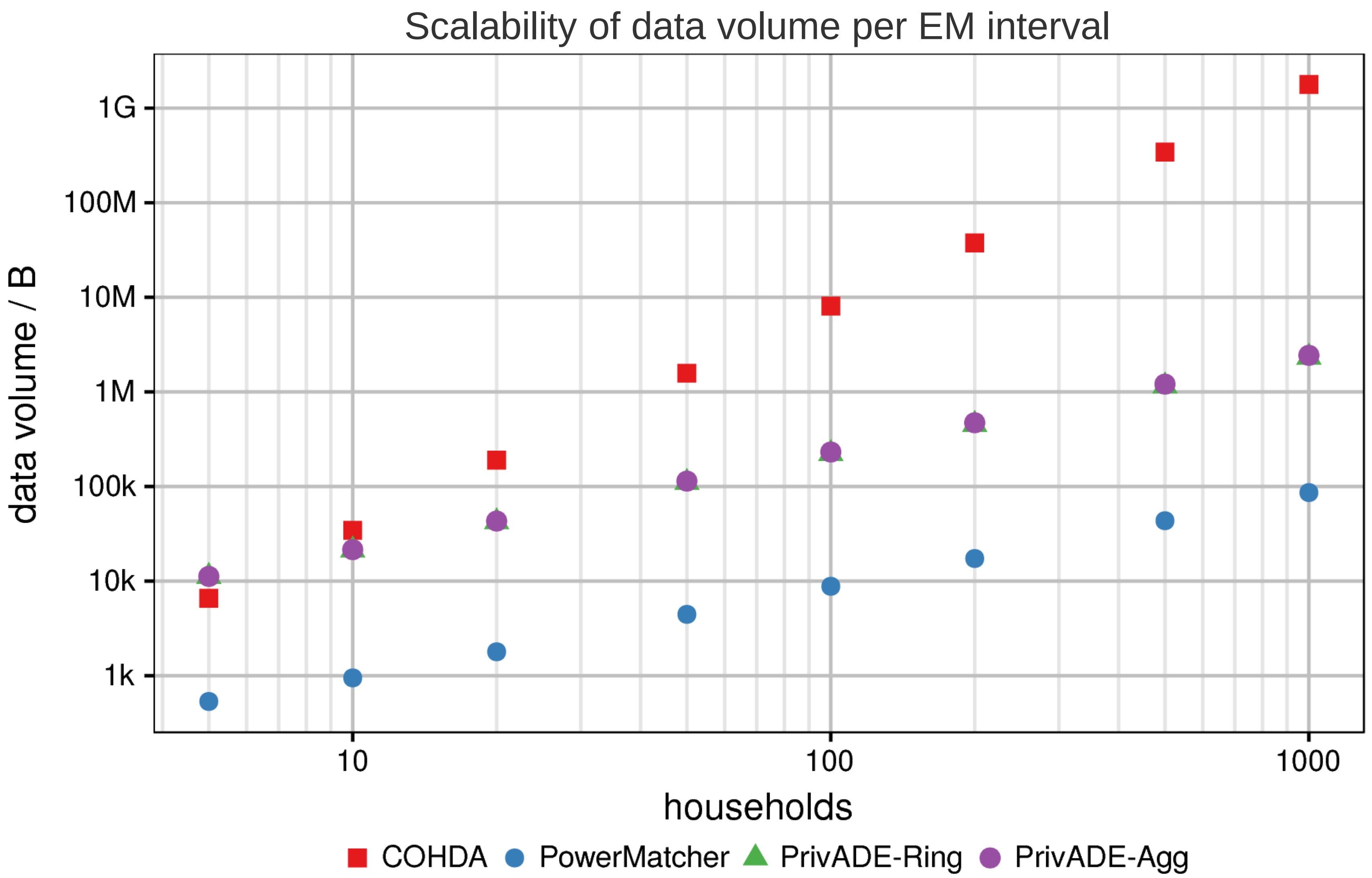

Evaluation: Scalability (Tree)

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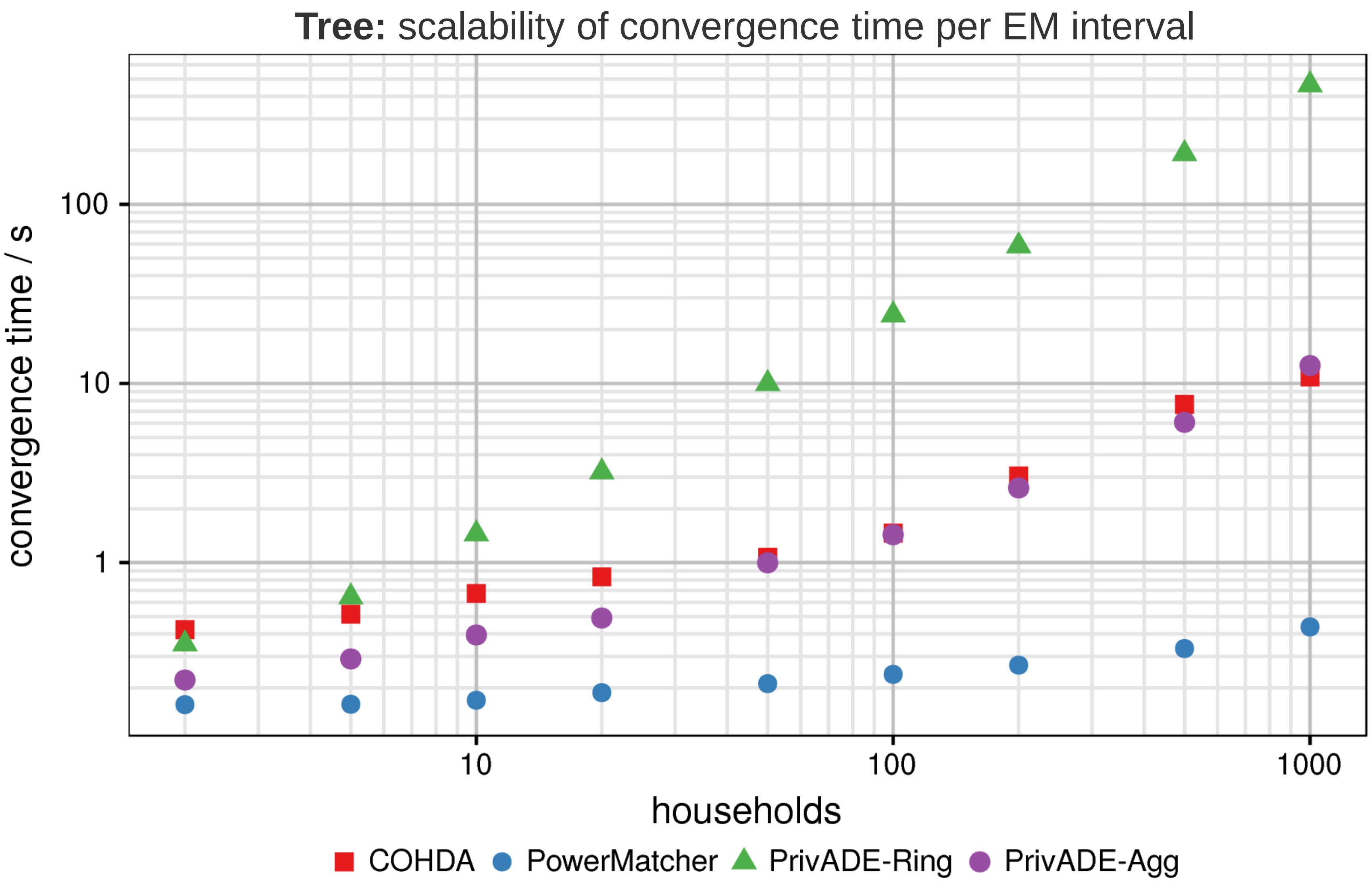

Evaluation: Scalability (LTE)

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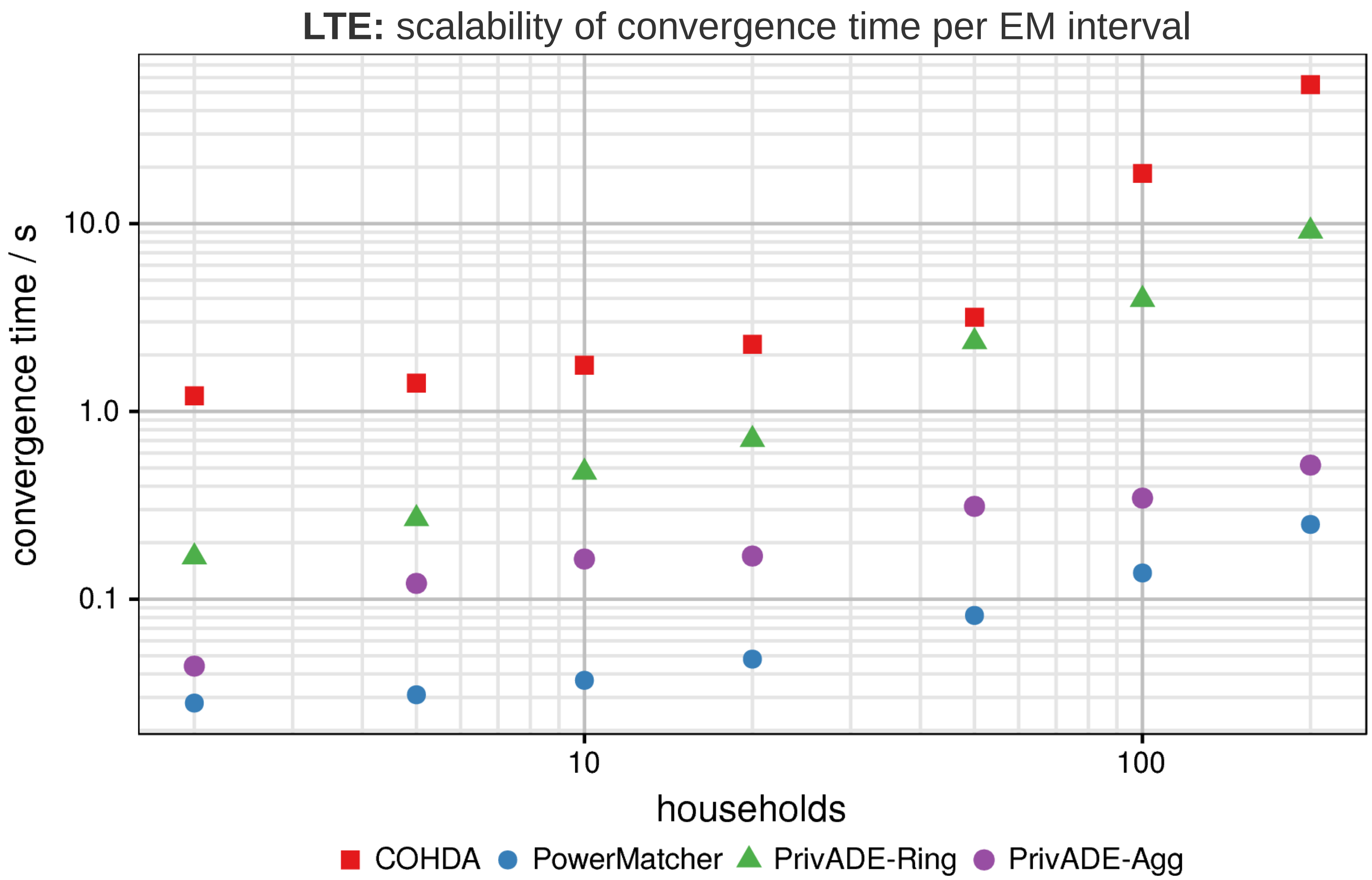

Evaluation: Scalability (PLC)

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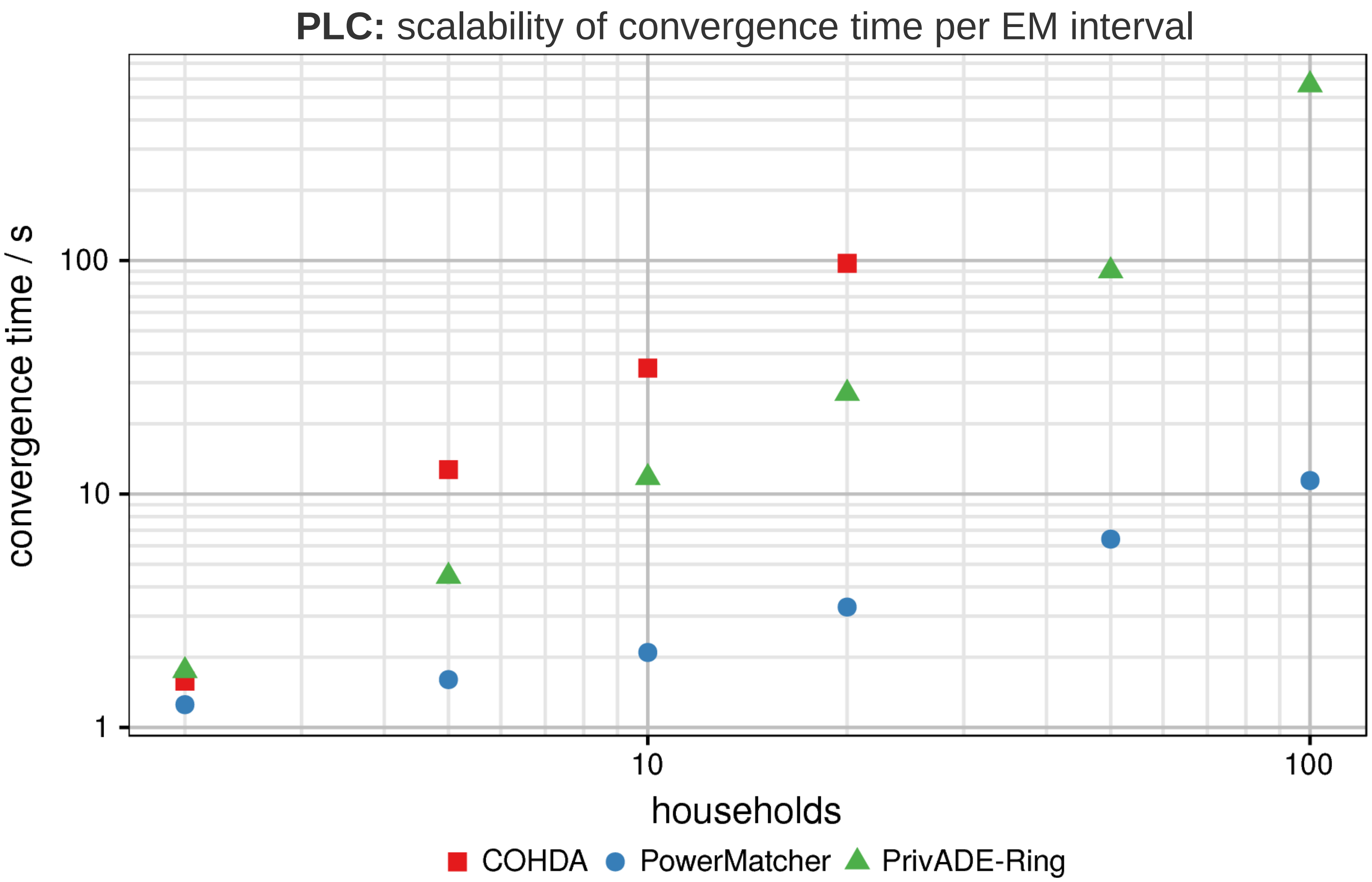

Evaluation: Privacy

- COHDA
  - Households publish information to each other
  - Every household has a consumption trace of all other households
  - **Privacy is at risk**
- PowerMatcher
  - Households send a bid to a concentrator
  - Concentrator has access to consumption traces and device states of households
  - **Privacy is at risk**
- PrivADE
  - Information is aggregated and encrypted
  - **Privacy is preserved at all times**

Evaluation: Comparison

Algorithm	EM Quality	Communicational Cost		Privacy
		Data Volume	Convergence Time	
COHDA	++	-	+ - (PLC)	-
PowerMatcher	+	++	++	-
PrivADE Ring	+++	+	- + (PLC)	+
PrivADE Aggregator	+++	+	+	+

Evaluation: Comparison

Algorithm	EM Quality	Communicational Cost		Privacy
		Data Volume	Convergence Time	
COHDA	23.5 %	$\mathcal{O}(H^2 \cdot \sqrt{H})$	$\mathcal{O}(\log H)$	No
PowerMatcher	19.7 %	$\mathcal{O}(H)$	$\mathcal{O}(1)$	No
PrivADE Ring	25.0 %	$\mathcal{O}(H \cdot \log\log H)$	$\mathcal{O}(H \cdot \log\log H)$	Yes
PrivADE Aggregator	25.0 %	$\mathcal{O}(H \cdot \log\log H)$	$\mathcal{O}(\log\log H)$	Yes

Conclusion

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- PLC
  - PrivADE Ring better than PrivADE Aggregator
  - Only few households possible
- LTE
  - COHDA floods the network
  - PowerMatcher and PrivADE can be chosen
- Wired Broadband technology
  - All Algorithms can be chosen

Choosing an Algorithm for Energy Management depends on Technology