# A Relational Network Framework for Interoperability in Distributed Energy Trading

Samuel Karumba*, Salil S. Kanhere*, and Raja Jurdak†
*UNSW, Sydney †QUT, Brisbane
{s.karumba, salil.kanhere}@unsw.edu.au, r.jurdak@qut.edu.au

***Abstract*—Blockchain-based approaches are increasingly being used to provide distributed trust and security in Distributed Energy Trading (DET). However, the state-of-the-art solutions lack scalability, privacy, interoperability, and often have large computational overheads hindering their mainstream adoption for sustainable development. To address these challenges, this paper proposes a multi-relationship network framework (RNF) that uses hypergraphs to organise participants in energy trading networks based on high-order relationships (rather than pairwise) for flexibility, interoperability, data privacy, and reduced resource consumption. Results indicate that the proposed framework outperforms the baseline in terms of: enabling value transfer across multiple blockchain-based DET systems; reducing computational costs and achieving energy efficiency for sustainable development.**

***Index Terms*—hypergraphs, blockchain, interoperability, distributed energy trading, multi-chain networks**

## I. Introduction

Energy trading has been identified as a critical element to underpin the shift from non-renewable to renewable energy sources (RES) for sustainable development [1]. Typically, renewable energy generation is distributed, dynamic and unpredictable, due to the stochastic nature of RES. Thus, as integration of renewable energy continues to grow, matching demand and supply efficiently becomes increasingly difficult.

In this regard, energy trading has evolved from the traditional centralised structure to a new Distributed Energy Trading (DET) paradigm. Recently, various studies [2]–[8] have proposed the use of blockchain in development of DET systems to establish distributed trust while eliminating trusted third parties. According to [9], there are over 122 startups pitching Blockchain-based DET (BDET) systems and a few pilots are already underway. However, the proposed solutions often overlap in terms of objectives, application, and at times are implemented on heterogeneous resource intensive (e.g memory, computational power, bandwidth, etc.) blockchain platforms. This imposes additional requirements such as interoperability, privacy, scalability and energy efficiency, which hinders sustainable development.

Today, there are no standard protocols or frameworks that allow different BDET systems to inter-operate. This lack of interoperability introduces secondary challenges: (i.) Double counting - similar to double spending in bitcoin [10], a kilowatt hour of renewable energy asset stands the risk of being traded on multiple BDET systems [11], (ii.) Data silos - where the value of an energy asset is locked in a platform-specific implementation, and (iii.) Data privacy and scalability - since data in BDET network is replicated to all nodes for provenance [12] this significantly reduces data confidentiality and impacts on the system scalability as the network grows.

In this work, we present a Relational Network Framework (RNF) based on hypergraph, a powerful tool for modeling multiple complex relationships beyond pairs. RNF proposes the following novel contributions: To achieve interoperability, we use hypergraph to generalise pairwise interactions in BDET systems; To ensure privacy and scalability, we derive an algorithm which dynamically groups all participating nodes into separate clusters; and finally, to facilitate value transfer across BDET systems, we design an atomic cross swap energy trading protocol implemented on a smart contract for asset exchanges.

We present performance evaluations using Hyperledger Caliper, to demonstrate that RNF allows efficient and reliable interoperability between multiple BDETs, while significantly reducing resource consumption and energy overheads.

## II. Relational Network Framework

To address interoperability, privacy, and scalability challenges of BDET systems the proposed framework is composed of three main layers namely: the network layer, clustering layer and the contract layer illustrated in Fig. 1. Each layer of RNF proposes a novel contribution in addressing the specific challenges highlighted in Section I.

### A. Network layer

The network layer is comprised of a set of communication services specified using protocol buffers [13] to provide network-neutral and platform-neutral communication mechanisms for interoperability between different blockchain systems. These communication service protocols are structured to provide data routing details such as node address, executing contracts, and verification policy from source to destination networks. To maintain trust between interoperating networks we use trust federation concept derived using hypergraphs to select a set of validator nodes with a higher degree (relationship weight).

### B. Clustering layer

In the clustering layer we collectively integrate and analyse all nodes from multiple BDET systems, independently

978-1-7281-6680-3/20/$31.00 ©2020 IEEE

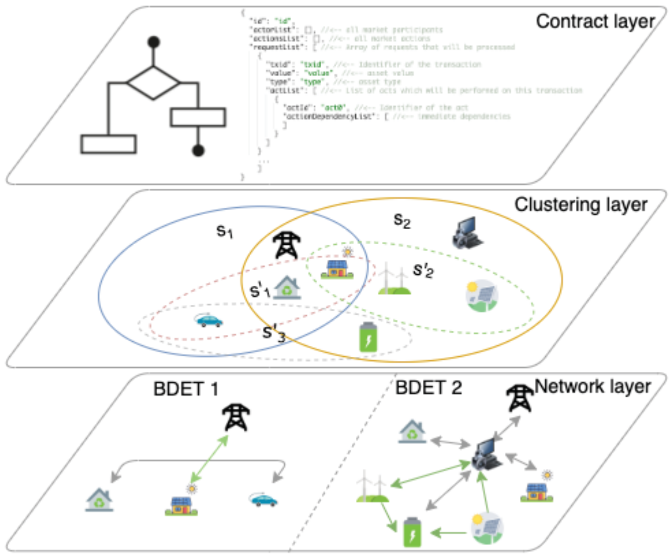



Fig. 1. Relational network framework

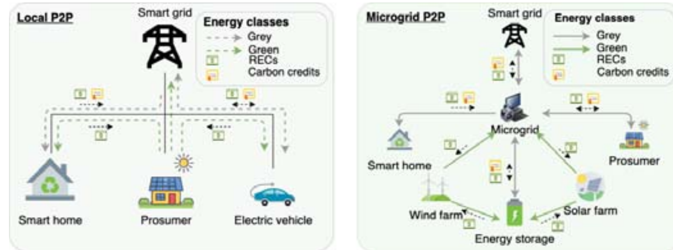
interrogating their physical capabilities (e.g. processing power, memory, blockchain platform, etc) and environmental characteristics (e.g. geographical, bandwidth, sectoral context, etc) to determine their primary and secondary relationships illustrated as $(s)$ and $(s')$ in Fig. 1 respectively. Additionally, a dynamic clustering algorithm is proposed to dynamically group nodes into similarity clusters, assign roles (endorsers, validators and committers), when particular relationships are invoked.

### C. Contract layer

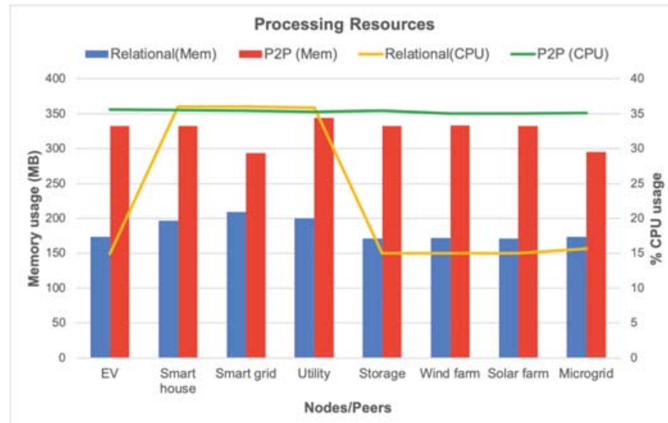
The contract layer specifies an atomic cross-chain swap asset exchange protocol for renewable energy trading. No actual value leaves any BDET system. The protocol handles the change of ownership of an asset in the source network and a corresponding change of ownership in the destination network. The resulting smart contracts are executed by endorser nodes determined by the clustering layer. Additionally, to preserve data privacy, transactions are recorded by a set of nodes (committers) that are dynamically determined by the clustering algorithm.

## III. Results

We consider BDET use cases for local peer-to-peer and microgrid, illustrated in Fig. 2(a), to conduct performance evaluations of RNF. Both BDET system were implemented using Hyperledger Fabric. To represent a real world scenario we assume the smart storage (SS), wind farm (WF), solar farm (SF) and electric vehicle (EV) nodes only use a smart meter to track energy flow. Technically, smart meters have limited processing power, thus, we allocated only 25% of the available CPU cycle while the rest of the nodes were allocated 100% of CPU cycle. To benchmark, we compared RNF against a single relationship BDET system where all nodes transact directly in peer-to-peer (P2P) exchanges.




(a) Experiment setup




(b) Processing resources

Fig. 2. Performance evaluation

Interestingly, RNF was observed to significantly reduce transaction storage usage by 30% and the processing power for non endorsing nodes by 39.8% in comparison with P2P, as illustrated in Fig. 2(b). We observe that the CPU usage on the endorsing nodes match that of all P2P nodes. This is because only endorsing node executes the smart contract unlike in P2P where all peers execute the same smart contract. This significantly reduces the overall computation cost and consequently, the energy overheads in RNF, making it more suitable for energy efficient BDET applications. Similarly, all committer nodes recording transactions in both BDET systems (smart home, prosumer and smart grid) also significantly reduced memory usage by 23% as compared to P2P. In summary to realise scalability, our results show that not all nodes in the network are required to execute transactions. Additionally each cluster stores fewer transaction making it easy for a new node to synchronise the transactions history.

## IV. Conclusion

We proposed a relational network structure, an adaptation of P2P networks which offers a secure privacy-preserving distributed energy trading network structure for local energy communities such as microgrids operating in different geographical locations to seamlessly trade energy across regions. We have demonstrated the feasibility of implementing the proposed relational network structure in a cross-chain energy trading system exhibiting scalability, improved level of privacy and better platform performance.

# References


[1] V. H. Nguyen, Y. Besanger, Q. T. Tran, and M. T. Le, "On the Applicability of Distributed Ledger Architectures to Peer-to-Peer Energy Trading Framework," *Proceedings - 2018 IEEE International Conference on Environment and Electrical Engineering and 2018 IEEE Industrial and Commercial Power Systems Europe, EEEIC/I and CPS Europe 2018*, 2018.

[2] A. Dorri, F. Luo, S. S. Kanhere, R. Jurdak, and Z. Y. Dong, "SPB: A Secure Private Blockchain-Based Solution for Distributed Energy Trading," *IEEE Communications Magazine*, vol. 57, no. 7, pp. 120–126, 2019. [Online]. Available: https://ieeexplore.ieee.org/document/8767089/

[3] LO3 Energy, "Transactive Energy: A New Approach for Future Power Systems," 2019. [Online]. Available: https://exergy.energy/wp-content/uploads/2019/03/TransactiveEnergy-PolicyPaper-v2-2.pdf

[4] Power Ledger, "WHITEPAPER We believe empowering individuals and communities to co-create their energy future will underpin the development of a power system that is resilient , low-cost , zero-carbon and owned by the people of the world ."

[5] C. Zhang, "Peer-to-Peer Energy Trading in Electrical Distribution Networks," 2017. [Online]. Available: https://orca.cf.ac.uk/109074/1/2018ZhangCPhD.pdf

[6] J. Murkin, R. Chitchyan, and A. Byrne, "Enabling peer-to-peer electricity trading," in *PROCEEDINGS OF ICT FOR SUSTAINABILITY 2016*, ser. ACSR-Advances in Comptuer Science Research, Grosso, P and Lago, P and Osseyran, A, Ed., vol. 46, 2016, pp. 234–235.

[7] T. Morstyn, N. Farrell, S. J. Darby, and M. D. McCulloch, "Using peer-to-peer energy-trading platforms to incentivize prosumers to form federated power plants," *Nature Energy*, vol. 3, no. 2, pp. 94–101, 2018. [Online]. Available: http://dx.doi.org/10.1038/s41560-017-0075-y

[8] K. Tanaka and R. Abe, "A Concept Proposal for Peer-to-Peer Power Exchange by Market Mechanism," in *2018 IEEE International Conference on Consumer Electronics-Taiwan, ICCE-TW 2018*, ser. IEEE International Conference on Consumer Electronics-Taiwan, 2018.

[9] S. Lacey, "Energy Blockchain Startups Raised $324 Million in the Last Year. Where's the Money Going?" 2018. [Online]. Available: https://www.greentechmedia.com/articles/read/energy-blockchain-startups-raised-324-million-since-2017#gs.28j981

[10] S. Nakamoto and S. Nakamoto, "Bitcoin: A peer-to-peer electronic cash system," http://bitcoin.org/bitcoin.pdf." [Online]. Available: http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.221.9986

[11] K. Nurul, J. J. Sikorski, K. Hadinoto, and M. Kraft, "Incorporating seller / buyer reputation-based system in blockchain-enabled emission trading application," *Applied Energy*, vol. 209, no. October 2017, pp. 8–19, 2018. [Online]. Available: https://doi.org/10.1016/j.apenergy.2017.10.070

[12] E. Androulaki, A. Barger, V. Bortnikov, S. Muralidharan, C. Cachin, K. Christidis, A. De Caro, D. Enyeart, C. Murthy, C. Ferris, G. Laventman, Y. Manevich, B. Nguyen, M. Sethi, G. Singh, K. Smith, A. Sorniotti, C. Stathakopoulou, M. Vukolić, S. W. Cocco, and J. Yellick, "Hyperledger Fabric: A Distributed Operating System for Permissioned Blockchains," *Proceedings of the 13th EuroSys Conference, EuroSys 2018*, vol. 2018-Janua, no. 1, 2018.

[13] E. Abebe, D. Behl, C. Govindarajan, Y. Hu, D. Karunamoorthy, P. Novotny, V. Pandit, V. Ramakrishna, and C. Vecchiola, "Enabling Enterprise Blockchain Interoperability with Trusted Data Transfer (industry track)," 2019. [Online]. Available: http://arxiv.org/abs/1911.01064