# 3D-DAG: A High Performance DAG Network with Eventual Consistency and Finality

Joe Zou[1], Zhongli Dong[2], Allen Shao[3], Peng Zhuang[4], Wei Li[2] and Albert Y. Zomaya[2]

***Abstract*—Blockchain has been widely recognized as the trust machine underpinning the Internet of Things(IoT). However, the poor performance of the existing mainstream platforms renders this expectation unattainable. New technologies like DAG and Hashgraph emerge as promising candidates to address the pressing issues, but their abilities in decentralized consensus are still in question. We propose a 3D-DAG model to address the trilemma of decentralization, scalability and security. Experiment results show that, by adopting the separation of concerns(SOC) architectural principle and a software defined chain(SDC) approach, 3D-DAG can meet challenging requirements expected by IoT applications.**

***Index Terms*—Blockchain, 3D-DAG, IoT, SOC, SDC, Trilemma**

## I. Introduction

In recent years, the Blockchain technology is emerging as the enabling technology for Internet of Value[1]. However, the transactions per second (TPS) of the mainstream blockchain platforms like Bitcoin and Ethereum are below 20 [2], inhibiting them from supporting any real life IoT applications. On the other hand, many emerging blockchain platforms such as EOS, IOTA and Hashgraph[3] claim that they can scale up to thousands or millions TPS. The potential risk is that such high TPS numbers may compromise consistency and security in their consensus process.

It is well known that there is a blockchain trilemma[4], which states that it is impossible to achieve decentralization, scalability and security at the same time. In this work, we propose a 3D-DAG model towards addressing the trilemma in IoT environment. Preliminary experiment results show that our 3D-DAG model can provide an effective platform to support DApps (Decentralized Applications) operation in IoT environment.

## II. Related Work

The consensus mechanism plays a central role in blockchain platforms and determines the performance, scalability and security of them. Typical consensus mechanisms include Bitcoin's Proof-of-Work(PoW), Peercoin's Proof-of-Stake(PoS), EOS's Delegated Proof-of-Stake(DPoS)[5]; and permissioned chain's Practical Byzantine Fault Tolerance(PBFT)[6], Paxos[7] and RAFT[8], etc.

Our literature review found that none of these existing consensus algorithms from both public blockchains and consortium/private blockchains meets the performance requirements expected by IoT applications.

## III. Proposed Solution

### A. Design Principle

As mentioned before, it is hard to achieve decentralization, scalability and security in blockchain simultaneously. We argue that this trilemma can be addressed by adopting the architectural design principle of separation of concerns (SOC).

The other design principle that we used is the software defined paradigm. We introduce Software-Defined Chain (SDC) in blockchain. The SDC approach will provide flexibility to address various requirements for different DApps.

### B. 3D-DAG Detailed Design

*1) Architecture Overview:* 3D-DAG is a network, which consists of a main blockchain, and multiple Directed Acyclic Graph(DAG) chains. There are three main roles in 3D-DAG. One is miner role. Miners not only produce blocks, but also validate and witness or consent the transaction of each DAG's transactions. The second role is the light node of different DAGs for transaction initiation. The last role is endorser, who executes smart contract and endorses the state result for complex state-transition transactions from DAG light node. Endorser also acts as state storage for each DAG. Each DAG can be defined at the time of creation based on chain template, so that we call it a Software-Defined Chain. SDC allows users to define endorsement and validation policies, as well as DAG chain parameters.

The key design decision is to use the miners of the main blockchain to secure all the DAG chains in the network. This design will offload the business application works to various DAGs from the main chain, thus improving DApp performance and the throughput of all DAGs. We further offload the smart contract execution work from miners to endorsers in order to balance the workload on the main chain.

*2) 3D-DAG Consensus Mechanism:* The unique aspect of 3D-DAG consensus is that miners only receive 1 3D-DAG coin for mining a block, but receive multiple times of rewards from transaction validations. Thus the bulk of the miner's

[1] Joe Zou (joezou@openstack.org.cn) is with Science and Technology Academy, China Institute Of Digital Asset.

[2] Zhongli Dong, Wei Li and Albert Y. Zomaya are with Center for Distributed and High Performance Computing, School of Information Technologies, The University of Sydney, Australia. Email: (zhongli.dong, weiwilson.li, albert.zomaya)@sydney.edu.au

[3] Allen Shao (ashao@aiib.org) is with Asian Infrastructure Investment Bank.

[4] Peng Zhuang (pzhuang@cn.ibm.com) is with IBM China.

**978-1-5386-4870-4/18/$31.00 ©2018 IEEE**

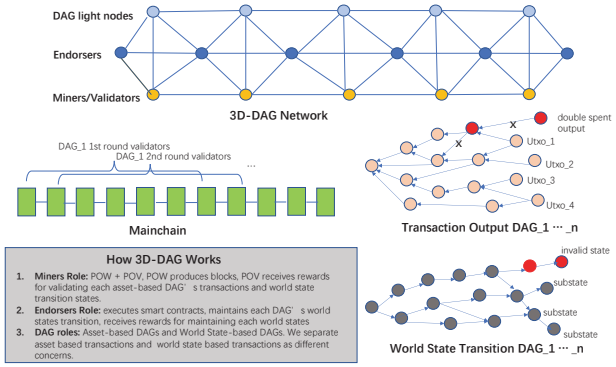


Fig. 1: The overview of 3D-DAG network.

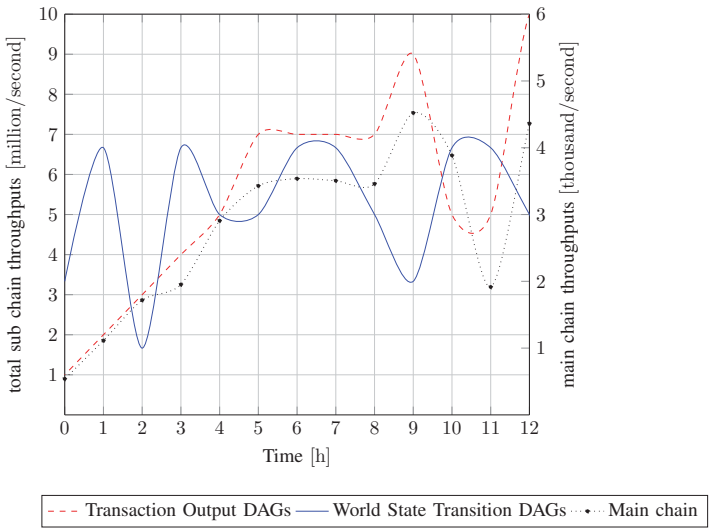


Fig. 2: 3D-DAG Throughputs 12 Hours Running.

computation power will be directed to perform the useful validation work, rather than hashing work only.

For any given DAG, assuming that it needs $n$ consenters, and more than $\frac{n}{2}+1$ votes for finalized a checkpoint. Starting from the miner who mined the genesis block of the main chain, up to $n$ miners who produced the subsequent blocks on the main chain will be selected as consenters. The consenters validate the transaction output in the DAG, omitting invalid transaction reference chains, including transactions with incorrect signatures or double-spend output transactions. Once a checkpoint cycle approached which defined using main chain's block height gap, each consenter broadcasts out a proposed finalized transaction outputs DAG, plus a hash value of the DAG attaching with the consenter's address. Each consenter will choose the majority transaction outputs DAG as the finalized transaction outputs DAG, and update their local database accordingly. The consenter with the lowest hashing value will receive $n$ 3D-DAG coins. The consenter group for the next validation and witness checkpoint cycle will include the miner who produced the block after the genesis block on the main chain, and up to $n$ miners who produce the subsequent blocks along the main chain, like a n-size slide window consenter selector sliding along the main chain. The same consenter selector algorithm goes on for the rest of the checkpoint cycles of a DAG.

## IV. Analysis and Experiments

*1) Analysis:* The 3D-DAG's voting process will get the majority votes from the validators to decide the finalized transaction output DAG. The DAG setting assumes that the majority validators are honest nodes. Therefore, agreement and validity can be guaranteed. The checkpoint cycle is predefined in the DAG's genesis unit, and is obeyed by the checkpoint process, thus the liveness is guaranteed.

The PoW and the consenter voting process, plus the Gas mechanism in smart contract can effectively fend-off the sybil or DDoS attacks.

In terms of performance, DAG light nodes can initiate transactions in parallel. The consensus process of DAG chains and the smart contract execution are carried out by miners and endorsers respectively on the main chain, which reduces load on DAG chains and also balances the load on the main chain, ensuring high TPS and throughput on 3D-DAG.

*2) Experimental Results:* We set up our main chain's transaction size as 512 byte, block size as 1MB and block generation interval as 30 seconds. We ran 200 sub DAG networks with 100 Transaction Output DAGs and 100 World State Transition DAGs, which all linked to the main chain. The workload of each sub chain varied from 1,000 to 8,000 TPS. After a uninterrupted 12 hour test run, Figure 2 shows the main chain can handle 1920 per second to 4210 per second transactions easily, with supports sub chains 1.1 million per second to 9.82 million per second total throughputs. With further tuning, 3D-DAG can adequately meet the demanding requirements of IoT applications.

## V. Conclusion

In this work, we've introduced a 3D-DAG solution and shown initial experimental results. Our approach provides high TPS and scalability that caters for IoT applications. Further studies will be conducted accordingly and security verification will also be addressed to ensure 3D-DAG is secure and robust.

## References

[1] C. Skinner, *Valueweb: How Fintech firms are using mobile and blockchain technologies to create the Internet of Value*. Marshall Cavendish, 2016.
[2] K. Croman, C. Decker, I. Eyal, A. E. Gencer, A. Juels, A. Kosba, A. Miller, P. Saxena, E. Shi, E. G. Sirer *et al.*, "On scaling decentralized blockchains," in *International Conference on Financial Cryptography and Data Security*. Springer, 2016, pp. 106–125.
[3] Hedera hashgraph. [Online]. Available: https://www.hederahashgraph.com/
[4] O. Dahlquist and L. Hagström, "Scaling blockchain for the energy sector," 2017.
[5] D. Larimer, "Delegated proof-of-stake (dpos)," *Bitshare whitepaper*, 2014.
[6] M. Castro, B. Liskov *et al.*, "Practical byzantine fault tolerance," in *OSDI*, vol. 99, 1999, pp. 173–186.
[7] L. Lamport *et al.*, "Paxos made simple," *ACM Sigact News*, vol. 32, no. 4, pp. 18–25, 2001.
[8] H. Howard, "Arc: analysis of raft consensus," University of Cambridge, Computer Laboratory, Tech. Rep., 2014.