Understanding the Scalability of Hyperledger Fabric

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ABSTRACT
The rapid growth of blockchain systems leads to increasing interest in understanding and comparing blockchain performance at scale. In this paper, we focus on analyzing the performance of Hyperledger Fabric v1.1 — one of the most popular permissioned blockchain systems. Prior works have analyzed Hyperledger Fabric v0.6 in depth, but newer versions of the system undergo significant changes that warrant new analysis. Existing works on benchmarking the system are limited in their scope: some consider only small networks, others consider scalability of only parts of the system instead of the whole.

We perform a comprehensive performance analysis of Hyperledger Fabric v1.1 at scale. We extend an existing benchmarking tool to conduct experiments over many servers while scaling all important components of the system. Our results demonstrate that Fabric v1.1’s scalability bottlenecks lie in the communication overhead between the execution and ordering phase. Furthermore, we show that scaling the Kafka cluster that is used for the ordering phase does not affect the overall throughput.

1. INTRODUCTION
Blockchain technology is moving beyond cryptocurrency applications [17, 14], and becoming a new platform for general transaction processing. A blockchain is a distributed ledger which is maintained by a network of nodes that do not trust each other. At each node, the ledger is stored as a chain of blocks, where each block is cryptographically linked to the previous block. Compared to a traditional distributed database system, a blockchain can tolerate stronger failures, namely Byzantine failures in which malicious nodes can behave arbitrarily.

There are two types of blockchains: permissionless and permissioned. The performance of both types of systems, however, lags far behind that of a typical database. The primary bottleneck is the consensus protocol used to ensure consistency among nodes. Proof-of-Work [14], for example, is highly expensive and achieves very low throughputs, whereas PBFT [9] does not scale to a large number of nodes [11]. Beside consensus, another source of inefficiency is the order-execute transaction model, in which transactions are first ordered into blocks, then they are executed sequentially by every node. This model, adopted by popular blockchains such as Ethereum and Hyperledger Fabric v0.6, is not efficient because there is no concurrency in transaction execution [15].

New versions of Hyperledger Fabric, namely version v1.1 and later, implement a new transaction model called execute-order-validate model. Inspired by optimistic concurrency control mechanisms in database systems, this model consists of three phases. In the first phase, transactions are executed (or simulated) speculatively. This simulation does not affect the global state of the ledger. In the second phase, they are ordered and grouped into blocks. In the third phase, called validation or commit, they are checked for conflicts between the order and the execution results. Finally, non-conflicting transactions are committed to the ledger.

The ordering phase is performed by an ordering service which is loosely-coupled with the blockchain. Hyperledger Fabric offers two types of ordering service: Solo which is used for development and testing, and Kafka service which is used for deployment in production system. The Kafka service forwards transactions to an Apache Kafka cluster [12]. By allowing parallel transaction execution, Hyperledger Fabric v1.1 can potentially achieve higher transaction throughputs than systems that execute transactions sequentially. However, it introduces an extra communication phase compared to the order-execute model, thus incurring more overhead.

In this paper, we aim to provide a comprehensive performance analysis of the execute-order-validate transaction model. To this end, we evaluate the throughput and latency of Hyperledger Fabric v1.1 in a local cluster of up to 48 nodes, running with Kafka ordering service. Our work differs from Blockbench [11], which benchmarks an earlier version of Hyperledger Fabric with order-execute transaction model. Its scope is more extensive than other recent works that examine the performance of Hyperledger Fabric v1.1 and later. For example, [6] does not consider the effect of scaling the Kafka cluster on the performance. Similarly, [7, 15, 16] fix the size of the Kafka cluster, and use fewer than 10 nodes. In contrast, we examine the impact of scaling Kafka cluster on the overall performance, using up to 48 nodes in a local cluster.

Hyperledger Caliper [3] is the official benchmarking tool
for Hyperledger Fabric. However, it offers little support and documentation on how to benchmark a real distributed Fabric setup with Kafka ordering service. Most of the documentation and scripts are considering the Solo orderer and a single client. To overcome this, we developed Caliper++ by enhancing Caliper with a set of scripts to configure, start and benchmark a distributed Fabric network with variable number and type of nodes.

In summary, our main contributions are as follows:

- We extend the Caliper, Hyperledger’s benchmarking tool, by adding support for distributed benchmarking. The result is Caliper++, a benchmarking tool that can start Fabric with varying sizes and configurations.
- We perform a comprehensive experimental evaluation of Fabric v1.1 using Smallbank smart contract. We scale the number of peers involved in all three transaction phases of the execute-order-validate model, by using up to 48 nodes in a local cluster.
- We show that endorsing peer — the one that performs the execute and validate phase — is the primary scalability bottleneck. In particular, increasing the number of endorsing peers not only incurs overheads in the execute and order phase, but also leads to degraded performance of the Kafka ordering service. On the other hand, we observe that scaling the Kafka cluster does not impact the overall throughput.

Section 2 discusses the background on blockchain systems, and the architecture of Hyperledger Fabric v1.1. Section 3 describes related works on blockchain benchmarking. Section 4 describes our benchmarking tool called Caliper++. Section 5 presents the experiment setup and results, before concluding in Section 6.

2. BACKGROUND

Blockchain networks can be classified as either permissionless (or public) or permissioned (or private). In the former, such as Ethereum [10] and Bitcoin [14], any node can join the network, can issue and execute transactions. In the latter, such as Hyperledger Fabric, Tendermint [8], Chain [2], or Quorum [5], nodes must be authenticated and authorized to send or execute transactions.

The ledger stores all historical and current states of the blockchain in the form of blocks linked together cryptographically. To append a block, all nodes must agree. More specifically, the nodes reach agreement by running a distributed consensus protocol. This protocol establishes a global order of the transactions. The majority of permissionless blockchains use computation-based consensus protocols, such as Proof-of-Work (PoW), to select a node that decides which block is appended to the ledger. Permissioned blockchains, on the other hand, use communication-based protocols, such as PBFT [9], in which nodes have equal votes and go through multiple rounds of communication to reach consensus. Permissioned blockchains have been shown to outperform permissionless ones, although its performance is much lower than that of a database system [11]. Nevertheless, they are useful for multi-organization applications where authentication is required but participating organization do not trust each other.

2.1 Hyperledger Fabric v1.1

Hyperledger Fabric v1.1 (or Fabric) is a permissioned (or private) blockchain designed specifically for enterprise applications. A blockchain smart contract, also called chaincode in Fabric, can be implemented in any programming language. A Fabric network comprises four types of nodes: endorsing nodes (or peers), non-endorsing nodes (or peers), clients, and ordering service nodes. These nodes may belong to different organizations. Each node is given an identity by a Membership Service Provider (MSP), which is run by one of the organizations.

Endorsing and Non-Endorsing Peers. A peer in the system stores a copy of the ledger in either GolevelDB [4] or CouchDB [1] database. It can be an endorsing peer if specified so in the Endorsement Policies; otherwise it is non-endorsing. Endorsing peers maintain the chaincode, execute transactions, and create (or endorse) transactions to be forwarded to the ordering nodes.

Endorsement Policies. An endorsement policy is associated with a chaincode, and it specifies the set of endorsing peers. Only designated administrators can modify endorsement policies.

System Chaincodes. In addition to running chaincode specified by users, Fabric peers run a number of pre-define system chaincodes. There are four system chaincodes: the life cycle system chaincode (LSCC) for installing, instantiating and updating chaincodes, the endorsement system chaincode (ESCC) for endorsing transactions by digitally signing them, the validation system chaincode (VSCC) for validating endorsement signatures, and the configuration system chaincode (CSCC) for managing channel configurations.

Channel. Fabric supports multiple blockchains that use the same ordering service. Each blockchain is identified by a channel, where members may consist of different sets of peers. Transactions on a channel can only be viewed by its members. The order of transactions in one channel is isolated from those of in another channel and there is no coordination between channels [6].

Ordering Service. The Ordering Service consists of multiple Ordering Service Nodes (OSNs). The OSNs establish a global order of transactions and construct blocks to be broadcast to peers. A block is created when one of the following conditions is satisfied: (1) the number of transactions reaches a specified threshold, (2) a specified timeout is reached; (3) the block size reaches a specified threshold. Endorsing peers receive blocks directly from the ordering service, while non-endorsing peers get blocks via a gossip protocol from other endorsing peers and from the ordering service. A Solo ordering service consists of a single node (or orderer) which serves all clients. A Kafka ordering service consists of a Kafka cluster to which OSNs forward transactions for ordering.

Client. A client sends transactions to endorsing peers, wait until it receives all endorsement from these peers, then broadcasts the endorsed transactions to OSNs.

Transaction. Separating the ordering service from the peers, Hyperledger Fabric v1.1 adopts the execute-order-validate (also called simulate-order-commit) model for executing a transaction. In contrast, Hyperledger Fabric v0.6 and other blockchain systems use the order-execute transaction model. In the next section, we describe the life cycle of a transaction in Fabric v1.1.
2.2 Transaction Life Cycle in Fabric

Fabric v1.1 employs the novel execute-order-validate transaction model which comprises three phases, as depicted in Figure 1.

**Endorsement phase.** A client submits a signed transaction to the endorsing peers. Each endorsing peer verifies if the client is authorized to invoke the transaction, then speculatively executes the transaction against its local blockchain state. This process is done in parallel without coordination among endorsing peers. Output of the execution, which consists of a read set and a write set, is used to create an endorsement message. The peer signs the endorsement and sends it back to the client.

**Ordering phase:** After collecting enough endorsements according to the endorsement policy, the client creates an endorsed transaction and forwards it OSNs. The ordering service orders the transactions globally. It then creates blocks and send them directly to endorsing peers or gossiping them to non-endorsing peers.

**Validation Phase:** When receiving a block, every peer validates transactions in the block against the endorsement policy of the chaincode. After that, for each transaction, the peer checks for read-write conflict by comparing the key versions in the read set are the same as those in the current ledger states. Any transaction that fails the validation or conflict check is marked as invalid. Invalid transactions are discarded and their effects to the blockchain states are rolled back. Finally, the block is appended to the peer’s local ledger.

3. RELATED WORK

There has been considerable interest in benchmarking Hyperledger Fabric. Blockbench [11] is the first framework for benchmarking permissioned blockchains. It divides blockchain stack into four layers: consensus, data, execution and application. It contains many micro and macro benchmarks for evaluating performance of every layer. However, Blockbench only supports Fabric v0.6 whose architecture is highly different to that of v1.1. Although the results reported in [11] cannot be extended to the new system, they present useful baseline performance of the order-execute transaction model.

E. Androulaki et al. [6] evaluate Fabric v1.1 using Kafka ordering service. They use a Kafka-based network of 5 endorsing peers, 4 Kafka nodes, 3 orderers, 3 Zookeeper nodes, and a varying number of non-endorsing peers. We note that non-endorsing peers do not play an active role in the transaction life cycle, as shown in Figure 1. Therefore, they are not a potential scalability bottleneck. We argue that the number of non-endorsing peers is not an important system parameter. As a consequence, [6] falls short in the analysis of system scalability.

Parth Thakkar et al. [16] also benchmark Fabric v1.1. However, their network is small, consisting of only 8 peers, 1 orderer and a Kafka cluster. The Kafka cluster runs on a single node, which does not fully capture the communication overhead in a real system. Furthermore, they do not consider scalability in terms of the number nodes. Ankur Sharma et al. [15] use the Solo orderer which is not meant to run in a real system. The network in [15] is small, with 4 peers, 1 client and 1 orderer distributed on 6 cluster nodes. Similarly, A. Baliga et al. [7] use the Solo orderer. Although they examine the effect of scaling the number of endorsing peers, they use a simple smart contract instead of ones representing realistic transactional workloads like Smallbank or YCSB.

4. CALIPER++

In this section, we present Caliper++, our extension to Hyperledger Caliper [3], the official benchmarking tool for Hyperledger Fabric.

4.1 Starting Up Fabric Network

The main challenge of benchmarking Kafka-based Fabric network at scale lies in starting up the distributed Fabric network. While Fabric v0.6 has only one type of nodes, represented by the peers themselves, Fabric v1.1 has six types of nodes: endorsing peer, non-endorsing peer, orderer, Kafka node (or broker), Zookeeper node, and client. This means there are more system parameters to consider. It also makes it more complex to automatically start up the network with all these components. In fact, we found limited official documentation on configuring a Kafka-based system. There are even fewer documentations on running Fabric on multiple physical nodes.

At its current state, Caliper [3] – the official benchmarking tool for Hyperledger blockchains – only supports testing on a local environment with a limited set of predefined Fabric network topologies, all of which use the Solo ordering service. Caliper++ supports additional functionalities for benchmarking Kafka-based Fabric network at scale. In particular, it provides a set of scripts to (a) auto-generate configuration files for any Fabric network topology, (b) bring up large-scale Kafka-based Fabric network across cluster nodes, (c) launch additional benchmarking tools at the operating system level, such as dstat, strace, perf. In addition, it allows benchmarking with distributed clients.

4.2 Benchmark Driver

Caliper++ implements the role of the client in Figure 1. It can be configured to issue a given number of transactions with a fixed rate. After sending one transaction, it schedules the next one after a fixed interval. The source code and documentation are available on GitHub at https://github.com/quangtdn/caliper-plus.
sending the next transaction after such interval that ensures the specified transaction rate is met. Responses from endorsing peers received during the execution phase are processed asynchronously in the client’s main event loop.

We note that Caliper++ implements a benchmark client (or driver) that is tightly coupled to the Fabric transaction workflow. This is different to Blockbench driver, which is separated from the blockchain network. In particular, Blockbench driver sends transactions via JSON APIs, waits for the transaction IDs from one of the blockchain nodes, then sleeps an appropriate amount of time before sending the next transaction. This driver is simply a workload generator, which is independent of the blockchain transaction processing workflow. Caliper++, in contrast, implements specific logic in which it waits and validates for responses from endorsing peers against endorsement policies. Another difference of Caliper++ is that it processes responses from multiple nodes for each transaction, as opposed to from a single node as in Blockbench driver.

5. PERFORMANCE ANALYSIS

In this section, we present our extensive benchmarking-based analysis of Hyperledger Fabric v1.1 using Caliper++. In this analysis, we focus on the following important performance metrics: throughput, latency and scalability. The throughput represents the number of successful transactions per second (tps). This is the most common metric to evaluate the performance of distributed systems, including distributed databases and blockchains. Latency represents the response time per transaction, in seconds. In our experiments, latency is taken as the average of the response time of all transactions. Scalability represents the changes in throughput and latency as the Fabric network scales up.

5.1 Experiments Setup

In this paper, a Hyperledger Fabric network topology is described by the number of endorsing peers (or peers, for simplicity) \( N \), number of clients \( C \) with mutual transaction send rate \( T \), number of Fabric orderers \( O \), number of Kafka brokers \( K \) and number of Zookeeper nodes \( Z \), as depicted in Figure 2. All the peers belong to different organizations (orgs), are endorsing peers and use GoLevelDB as the state database. The endorsement policy contains all \( N \) endorsing peers. The block size is set to 100 transactions/block, and the timeout is set to 2s.

In a Kafka ordering service, the Fabric orderers only act as the proxies forwarding transactions to the Kafka brokers which do the actual ordering. Since only the number of Kafka brokers affects directly the ordering capacity of the ordering service, we fix the number of Fabric orderers to \( O = 4 \) throughout our experiments and vary the number of Kafka brokers \( K \) to assess the impact on scaling Fabric. We shall see that increasing the number of Fabric orderers strongly degrades the system throughput due to communication overhead.

For each Kafka broker, we set \( \text{min.insync.replicas} = 2 \), and \( \text{default.replication.factor} = K - 1 \). This configuration means that any transaction is written on \( K - 1 \) Kafka brokers, and committed after being successfully written on two Kafka brokers. If \( \text{default.replication.factor} < K - 1 \), there would be idle Kafka brokers not participating in the ordering phase. In practice, these idle Kafka brokers are reserved for ordering other channels in the Fabric network. However, in our testing environment with single-channel ordering service is not meaningful to have idle Kafka brokers. Furthermore, setting a high value, such as \( K - 1 \), for \( \text{default.replication.factor} \) also increases the fault-tolerance of the Kafka cluster, thereby providing us insights on the trade-offs between performance and fault-tolerance.

Figure 2: Hyperledger Fabric Setup

Figure 3: Throughput while scaling network size
We use the popular OLTP database benchmark Smallbank [13] in our experiments. Simulating typical asset transfer scenario and a large class of transactional workloads such as TPC-C in general, Smallbank is suited to test the Fabric system at scale. Furthermore, Smallbank is one of the two macro-benchmark workloads used in Blockbench [11] to benchmark Hyperledger Fabric v0.6, and thus gives us a stand for comparison between v0.6 and v1.1.

The experiments were run on a 48-node commodity cluster. Each server node has an Intel Xeon E5-1650 CPU clocked at 3.5 GHz, 32 GB of RAM, 2 TB hard drive and a Gigabit Ethernet card. The nodes are running Ubuntu 16.04 Xenial Xerus.

### 5.2 Determining the Saturation Point

In this section, we examine the capacity of the Fabric system. We vary the number of peers $N$, while keeping the number of clients equal to the number of peers, $C = N$, and gradually increase the total request rate until the end-to-end throughput is saturated. The saturation request rate $C \times T$ determined in these experiments is used in later experiments where we investigate the system’s performance while scaling the number of peers or Kafka brokers.

Firstly, we use a number of Kafka ordering brokers equal to the number of peers, $K = N$, and incrementally increase the total request rate until the throughput significantly degrades. The total throughput and latency are shown in Figure 3a and Figure 4a, respectively. We observe that the throughput degrades as the network scales up. All network sizes exhibit throughput degradation on request rates equal or higher than 400 tps. The network with 16 peers and Kafka orders is saturated with a request rate of 300 tps. The latency exhibits similar behavior, except on the 16 peers network where it starts to degrade from a request rate of 250 tps. The fixed request rates of $C \times T = 300$ tps and $C \times T = 400$ tps represent, in general, the points before and after the saturation, respectively. These request rates are chosen to perform evaluate the costs of increasing the number of peers or Kafka brokers.

Secondly, we fix the number of Kafka brokers $K$ and the client’s request rate to $T = 30$, while scaling the number of peers and clients $N = C$. The network is linearly enlarging in terms of both number of peers and total request rate. The total throughput and latency are shown in Figure 3b and Figure 4b, respectively. We observe that the throughput decreases and the latency increases when the network consists of more than 8 peers. Moreover, from $N = 12$ on all the tested network topologies, the throughput decreases drastically. The cumulative request rate of the system at this point is 360 tps.

Thirdly, we show that the client does not represent a bottleneck by running the experiments with a single client, $C = 1$, while scaling the number of peers and Kafka orders, $N = K$. The throughput, depicted in Figure 5, exhibits similar performance as the throughput with more than one client.

We observe similar patterns in all the above experiments, exposing the same saturation points in all Fabric network topologies under evaluation. This suggests that the saturation of the networks is caused by Fabric’s incapability of handling request rates beyond certain thresholds, rather than the communication or capacity bound of clients. Before the saturation point, the throughput of the Fabric network with multiple clients is always slightly better than that of Fabric network with a single client because, for the later, the single client has to send a larger set of request transactions.
and accordingly incurs more overhead.

To further validate our observation, we profile the systems with dstat tool to get CPU and memory utilization, and networking traffic on each node. Figure 7 depicts the resource utilization of different types on nodes in a Hyperledger Fabric network consisting of $N = 8$ peers, $K = 8$ Kafka nodes, $O = 4$ Fabric orderers, $Z = 3$ Zookeeper nodes and $C = 1$ client. The trends are consistent with the benchmarking setting, where the clients use eight different transaction request rates in the range $C \times T \in [200, 425]$. Each transaction request benchmark lasts for 120s. We observe that client and peer resource utilization, especially at CPU and networking level, increases with the transaction rate, as expected.

However, none of the Fabric network nodes is fully utilizing the hardware. The CPU utilization is below 40% for all nodes. While the clients and the peers use up to 30% of the CPU, some Kafka brokers and Zookeeper nodes use less than 5%. Memory utilization is also low. Only the front-end orderer uses close to 20% (or around 6 GB) to buffer the requests.

At networking level, the client, peers, Fabric orders and Kafka leaders exhibit the highest traffic. This traffic represents both sent and received bytes. The high traffic of Fabric orderer is explained by its double role, as receiver of requests from the client and as dispatcher of requests to Kafka, as shown in Figure 2. The high traffic of some Kafka nodes, or leaders, is explained by their double role, as managing the replication inside the Kafka cluster and as connecting links to the Fabric orderers. Compared to the maximum capacity of 125 MB/s of the Gigabit Ethernet, the traffic of Kafka leaders is below 50% or 60 MB/s, on average.

### 5.3 Overhead of Fabric Orderers

In this section, we investigate the impact of scaling the number of orderers. We take the network size with the lowest performance in the previous section, $N = K = 16$, and increase the number of orderers from $O = 4$ to $O = 10$. The throughput plotted in Figure 6 shows that the network with more orderers is performing worse. Increasing the number of orderers only increases the communication overhead, since orderers act as proxies broadcasting transactions rather than ordering.

### 5.4 Scaling the Number of Fabric Peers

In this set of experiments, we fix the request rate and investigate the impact of increasing the number of peers. We fix the total request rate to $C \times T = 300$ and $C \times T = 400$, separately, as discussed in Section 5.2. We fix the number of Kafka orderers on a value in the set $\{4, 8, 16\}$, and increase the number of peers up to 24. The average throughput and latency of each experimental setting is shown in Figure 8 and 9, respectively.

Increasing the number of peers strongly degrades the system’s throughput and limits Fabric’s scalability. To understand the bottlenecks, we examine the system logs and observe that scaling the number of peers incurs overhead in both the endorsement and ordering phases within the transaction flow.

Firstly, increasing the number of endorsing peers means that each client has to wait for a larger set of endorsements from all the peers to prepare the endorsement transaction. Examining the logs of Caliper’s clients, we observe that the clients return a large number of timeout errors while collecting the endorsements from peers and, accordingly, discard those transaction proposals. As a result, clients send endorsement transactions to the orderers at a much lower rate due to dropped transactions and the time overhead for collecting endorsements.

Secondly, the orderers broadcast blocks to all the endorsing peers for validation. Hence, more peers correspond to more communication overhead for the ordering service. In the experiment with a fixed request rate of 400 tps and $N = 24$ peers, we observe that Caliper’s clients start to return timeout errors while sending endorsement transactions to orderers. Further examining the orderers’ logs shows that the rate at which orderers receive endorsement transactions from clients dominates the rate of returning confirmed transactions in the form of blocks. In particular, whenever an orderer broadcasts a transaction to the Kafka cluster, it logs a message "/channel: mychannel Enqueueing envelope...". After the transaction is ordered by the Kafka and returned to the orderer for batching blocks, the orderer logs a message "/channel: mychannel Envelope enqueued successfully", followed by the immediate acknowledgement from the client that have just sent such transaction, "/channel: mychannel Broadcast has successfully enqueued message of type ENDORER_TRANSACTION from...". We count the number of such messages and compute the ratio $r = \frac{\text{number of "Enqueueing envelope..." messages}}{\text{number of "Envelope enqueued successfully" messages}}$. On average, this ratio is larger than 1.7, suggesting that the Kafka-based ordering service may only order and return to the commit phase $1/1.7 \approx 58.8\%$ of the amount of endorsement transactions it receives. As increasing the number of peers only lowers the endorsement transaction rate sent to orderers, as explained in the previous paragraph, and there is no interaction between peers and Kafka cluster, the bottleneck of orderers totally lies in the communication overhead for broadcasting to a large number of peers.

Letting aside these issues, the scalability for Hyperledger Fabric v1.1 improved against v0.6. Blockbench [11] shows that v0.6 fails with more than 8 peers. However, the current performance of Hyperledger Fabric v1.1 is still limited in terms of real-world applications. For example, other two popular blockchain systems, Ethereum and Parity, scale
up to more than 32 nodes while maintaining the steady throughput around 100 and 50 tps respectively [11].

5.5 Communication Overhead within Kafka Cluster

In this experiment, we fix $N = K = C = 16$ and investigate the effect of communication within the Kafka cluster on Fabric’s throughput, by comparing two extreme settings. In the Kafka-based Fabric ordering service, a transaction must be written to default.replication.factor number of Kafka brokers, and committed after min.insync.replicas number of successful writes. In our first setting, we set these two values to their maximum, default.replication.factor = 15 and min.insync.replicas = 14, to cause a high communication cost inside the Kafka cluster. In the second setting, we set these two values to the minimum possible, default.replication.factor = 1 and min.insync.replicas = 1, while violating fault-tolerance. Under the least communication setting, a transaction is committed immediately after being written to one Kafka broker. After that, the Kafka cluster still writes the transaction to the remaining Kafka brokers, but the Fabric’s transaction flow does not halt for this operation, thereby incurring minimal communication overhead from Kafka service. Therefore, the gap between these two cases relatively represents the overhead of the Kafka ordering service under full fault-tolerance, represented by default.replication.factor = $K - 1$.

The results, depicted in the Figure 10, show that the throughput of the most intensive communication setting is always dominated by the throughput of the least communication setting. However, as the difference is negligible, we conclude that intra-cluster Kafka communication does not affect the overall throughput of Fabric.

5.6 Scaling Kafka brokers

In this set of experiments, we fix the number of peers $N$, and investigate the effect of increasing the number of Kafka brokers. We fix the total request rate to $C * T = 300$ and $C * T = 400$. For each value of $N \in \{4, 8, 16\}$, followed by the same number of clients, we vary the number of Kafka brokers. The average throughput and latency of each setting is shown in Figure 11 and Figure 12, respectively.

Generally, scaling the Kafka brokers does not impact the throughput pattern or scalability of the system.
Figure 8: Throughput while scaling the number of peers

(a) Throughput for fixed request rate $C \times T = 300$ tps

(b) Throughput for fixed request rate $C \times T = 400$ tps

Figure 9: Latency while scaling the number of peers

(a) Latency for fixed request rate $C \times T = 300$ tps

(b) Latency for fixed request rate $C \times T = 400$ tps

6. CONCLUSION

In this work, we presented our benchmarking tool Caliper++, which is specifically designed to examine the scalability of Hyperledger Fabric v1.1, a permissioned blockchain platform. Using Caliper++, we have conducted a comprehensive study on the scalability performance of Fabric. By identifying major bottlenecks of system, we hope that the survey and benchmarking tool would serve to guide the design and implementation of Hyperledger Fabric in the future.

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Figure 10: Kafka communication test

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Figure 11: Throughput Performance
Figure 12: Latency Performance