Validating Consensus Algorithms in IoT Networks: Design and Implementation of a Scalable Blockchain Network Emulator

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Abstract

This demo presents a novel, scalable blockchain network emulator designed to verify and evaluate the performance of consensus algorithms in Internet of Things (IoT) networks. The emulator combines low-cost, embedded IoT devices with flexible blockchain network simulation software, providing a realistic environment that closely mirrors practical IoT blockchain networks. By using this emulator, blockchain developers and researchers can accurately assess the performance of their consensus algorithms, overcoming the limitations and deviations often encountered with traditional software simulation or virtual machine-based simulations. The emulator's efficacy is demonstrated through the testing of two recent consensus algorithms, Streamlet and HotStuff, with results closely aligning with theoretical predictions. This work provides a valuable tool for the practical assessment of blockchain systems within IoT scenarios.

Introduction

Blockchain technology showcases immense potential across various Internet of Things (IoT) applications. Evaluating the performance of blockchain systems within IoT networks, particularly in aspects such as the consensus algorithm, block data structure, and communication protocols, remains a critical area of research. Traditional methods for blockchain system evaluation often involve software simulations like Matlab and NS3 or virtual-machine-based simulations, such as Docker. However, these approaches often fail to accurately emulate real-world IoT networks due to their inability to account for practical constraints like hardware resources (CPU and memory), network bandwidth, packet loss rate, and delay. This discrepancy leads to significant deviations in the performance of the blockchain system in practical deployment compared to the simulated performance.

In this work, we introduce a scalable blockchain network emulator that bridges this gap. This emulator, comprised of low-cost, embedded IoT devices and flexible network simulation software, accurately emulates the operational scenarios of practical IoT blockchain networks. This innovative approach allows blockchain developers and researchers to validate and assess their consensus algorithms within practical IoT network parameters, providing a more accurate reflection of real-world performance than traditional software simulation.

System Design

The blockchain network emulator comprises two main components: hardware and software. As depicted in Fig. 1, the hardware consists of a cluster of embedded IoT devices that function as nodes in a realistic IoT network. These devices can be interconnected via wired or wireless networks based on specific emulation requirements. Each IoT node operates a suite of emulation software, including a network controller, a blockchain, and the consensus algorithm under evaluation.

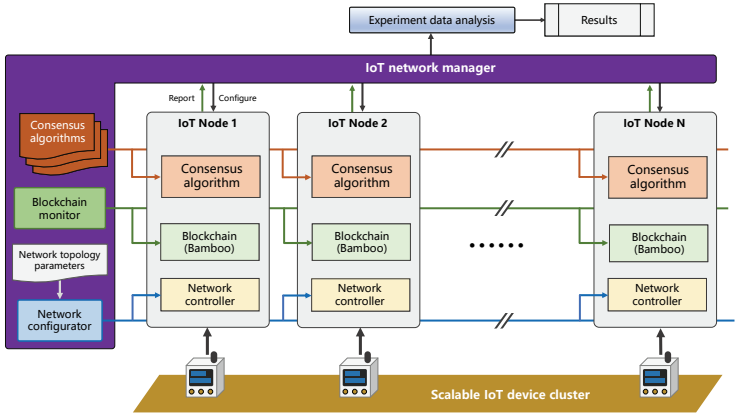

Fig. 1: The system design of the blockchain network emulator.

The network simulator is developed on the Linux *tc* (traffic control) tool, which controls parameters such as latency, bandwidth, and packet loss rate for outgoing network traffic from the container. A centralized network controller configures the network parameters for all containers, based on real-world IoT network parameters collected for emulation. The power consumption of the blockchain software can be measured by the linux *powertop* tool.

In addition, we implement the blockchain based on an open-source project named "Bamboo". This project offers a flexible blockchain framework with pluggable consensus algorithms. A centralized blockchain monitoring system is utilized to measure the performance of all blockchain nodes, including throughput and delay. This emulation system, therefore, can accurately simulate a practical IoT blockchain network with a scalable number of nodes.

Implementation

Our IoT network emulator is implemented using off-the-shelf industrial-grade embedded development kits named NanoPi. As illustrated in Fig. 2, the NanoPi Neo2 is a low-power embedded device equipped with an ARM-A53 (quad-core @1.5GHz) CPU and 1GB of memory, which are typical hardware configurations for IoT devices. Each NanoPi Neo2 board is encased in a metal housing and features an OLED screen for displaying its status information. All the blockchain nodes operate on the Ubuntu Core 16.04 operating system.

The IoT blockchain network consists of 48 NanoPi Neo2 nodes, connected to a network router either via Ethernet or WiFi, based on the specific requirements of the emulation. These nodes operate a set of emulation software, including a network controller and the specific blockchain and consensus algorithm being tested, delivering a realistic emulation of IoT blockchain operations. This setup provides an efficient and accurate environment for testing and evaluating the performance of various consensus algorithms in practical IoT networks.

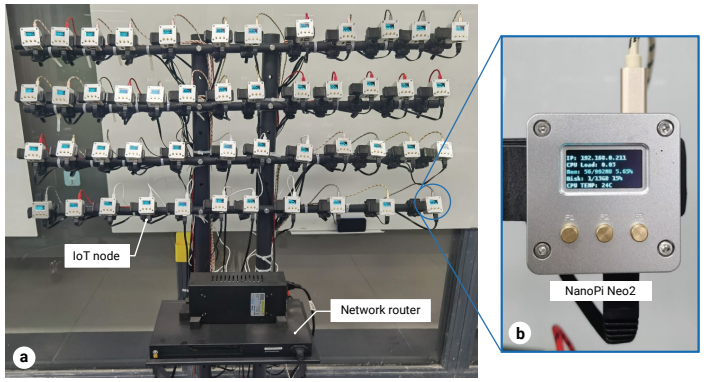

Fig. 2: The implementation and hardware details of the blockchain network emulator.

Evaluation

To evaluate the emulator's performance, we conducted tests on two recent consensus algorithms: Streamlet and HotStuff. These tests, carried out with different numbers of consensus nodes (4 and 8), measured transaction confirmation delay and throughput. The delay quantifies the time elapsed from the moment a node transmits a transaction until the moment the block containing this transaction is decided by the consensus algorithm. Throughput, on the other hand, gauges the speed at which the consensus nodes can confirm transactions using the tested consensus algorithm.

During the experiments, we utilized 8 IoT nodes to function as clients, issuing transactions to the blockchain network at an adjustable rate. We incrementally increased the transaction issue rate and measured the delay and throughput of the two consensus algorithms. As depicted in Fig. 3, the experimental results closely matched the theoretical analyses presented in their original papers. These findings suggest that our proposed blockchain network emulator is a reliable and practical tool for verifying and evaluating blockchain systems within IoT scenarios.

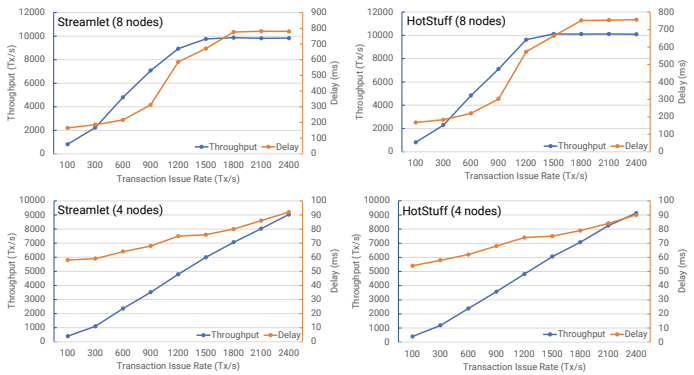

Fig. 3: Emulation results of Streamlet and HotStuff.

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