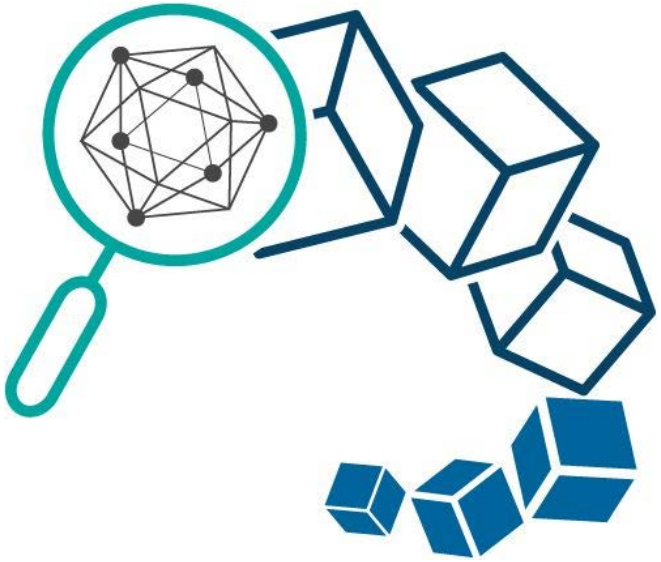
A Survey of IoT Applications in Blockchain Systems: Architecture, Consensus and Traffic Modeling



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2020-08

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Introduction

- Blockchain
  - Cryptocurrencies
  - Online payment
  - Data tracking
- IoT
  - Smart home appliances
  - Indoor and outdoor sensors
- IoT Blockchain
  - Record transaction data
  - Optimize system performance
  - Additional security
  - Automatic transaction management

Introduction

- Trend of IoT Blockchain
  - Popularity
  - Range of Applications
  - Development of underlying technology
  - Business Model
- Challenge of IoT Blockchain
  - Resource constraints
    - Computational power, Storage, Bandwidth
  - Scalability

Problem Statement

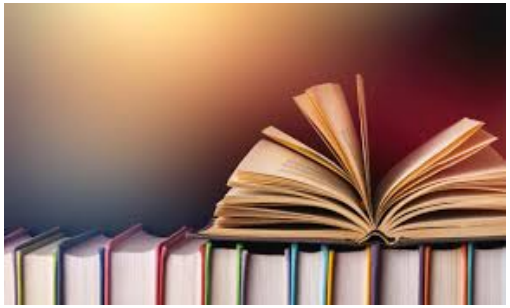
- Architecture needs to support an enormous number of IoT devices
- Blockchain consensus mechanism need specifically design
  - Limited storage
  - Low computing capability
- Traffic modeling is needed
  - Realize high system performance
  - Optimization

Related Work

- Some previous work has discussed the integration of IoT and blockchain
- ***Christidis et al.*** investigated smart contracts of IoT-blockchain.
- ***Marco et al.*** conduct a systematic literature review of blockchain
- ***Alfonso et al.*** categorize IoT blockchains into different domains and survey their challenges
- ***Dorri et al.*** present study of a smart home efficiencies and the integration of blockchain

Related Work

- Previous work provides surveys of IoT networks and blockchain systems separately
- We survey the integration of IoT and blockchain.
- Provides a survey of traffic analysis of IoT blockchain
  - Not been done before

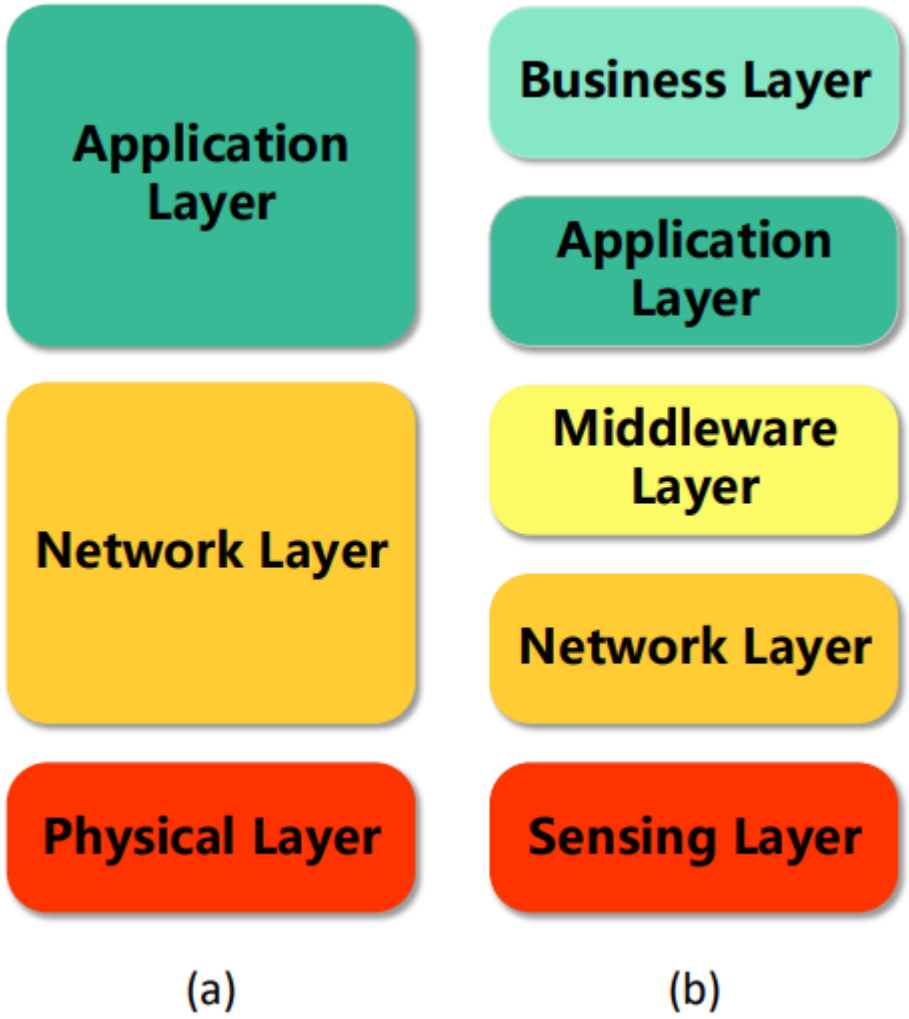


Contribution

1. We survey IoT-blockchain applications and propose a general IoT-blockchain architecture.
2. We make comparisons of current consensus mechanism and show their strengths and shortcomings in IoT blockchains
3. We analyze the current blockchain traffic models and propose a traffic model of IoT-blockchain systems

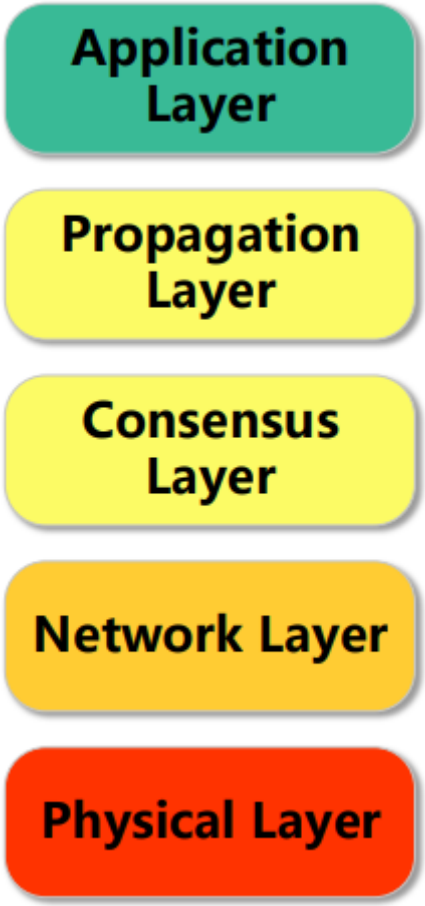
Architecture

- IoT architecture
  - Physical layer
    - Sensor
    - RFID
    - NFC
    - Mobile phone
  - Network layer
    - 4G, 5G
    - WiFi
    - Bluetooth
  - Application layer
    - Services



Architecture

- Blockchain architecture
  - Summarizes from previous work
  - Physical layer
    - Full node
    - Light node
  - Network layer
    - P2P network
  - Consensus layer
    - Consensus mechanism
  - Propagation layer
    - Gossip protocol
    - Kademlia
  - Application layer
    - Services



Architecture

Comparison of blockchain applications

Blockchain Application	Consensus Mechanism	TPS (tx/sec)	Releases date
Bitcoin	PoW	7	Jan 2009
Litecoin	PoW	56	Oct 2011
Bitshares	DPoS	17	Jul 2014
NEO	DBFT	1000	Feb 2014
Ethereum	Pow/PoS	15	Jul 2015
Hashgraph	Hashgraph	10000	Jul 2017
Tangle	DAG	800	Apr 2018
Ripple	Ripple	1700	May 2018
EOS	DPoS	3000	Jun 2018
QTUM	PoS	70	Jul 2018
Futurepia	DDPoS	300000	Sep 2018
Casper	PoS	10000	Jan 2019
Monoxide	PoW with Chu-ko-nu Mining	15.6	Feb 2019

Architecture

- Comparison between IoT-Blockchain Applications

IoT-Blockchain	Service	Blockchain	Consensus	IoT devices	Company size
Filament [Filament 2018]	Transaction service to embedded IoT	Hardware-based Consortium Blockchain	PoW	Blocklet USB Enclave, Blocklet Chip	40 milions market cap
Xage [Xage 2018]	Security service	Fabric	Fabric consensus	Broker, Enforcement Point	300 milions market cap
UniquID [UniquID 2018]	Integrated service to IoT and blockchain	Litecoin	PoW	Sensors, Actuators, Appliances	Open source project
LeewayHertz [LeewayHertz 2019]	IoT-blockchain solutions	Public blockchain	PoW	Robots, Audio devices	More than 10 years in operations
ElectriCChain [ElectriCChain 2018]	Process data of solar panel	SolarCoin	PoS	Solar panel	Open source project
Atonomi [Atonomi 2019]	IoT-blockchain solutions	Atonomi	Atonomi consensus	Smart devices, Smart home	Leading provider of IoT data security
LO3 Energy [LO3 2018]	Solar energy marketplace	Public blockchain solution	PoW	Grid Edge, Solar plane	1 million in revenue annually
Slock.it [sloct.it 2018]	Commission shop	Ethereum	PoW	Electronic lock	1.5 millions in revenue annually
JD.com [JDChain 2019]	Blockchain platform	BFT blockchain	BFT	IoT devices	1.7 trillions market cap

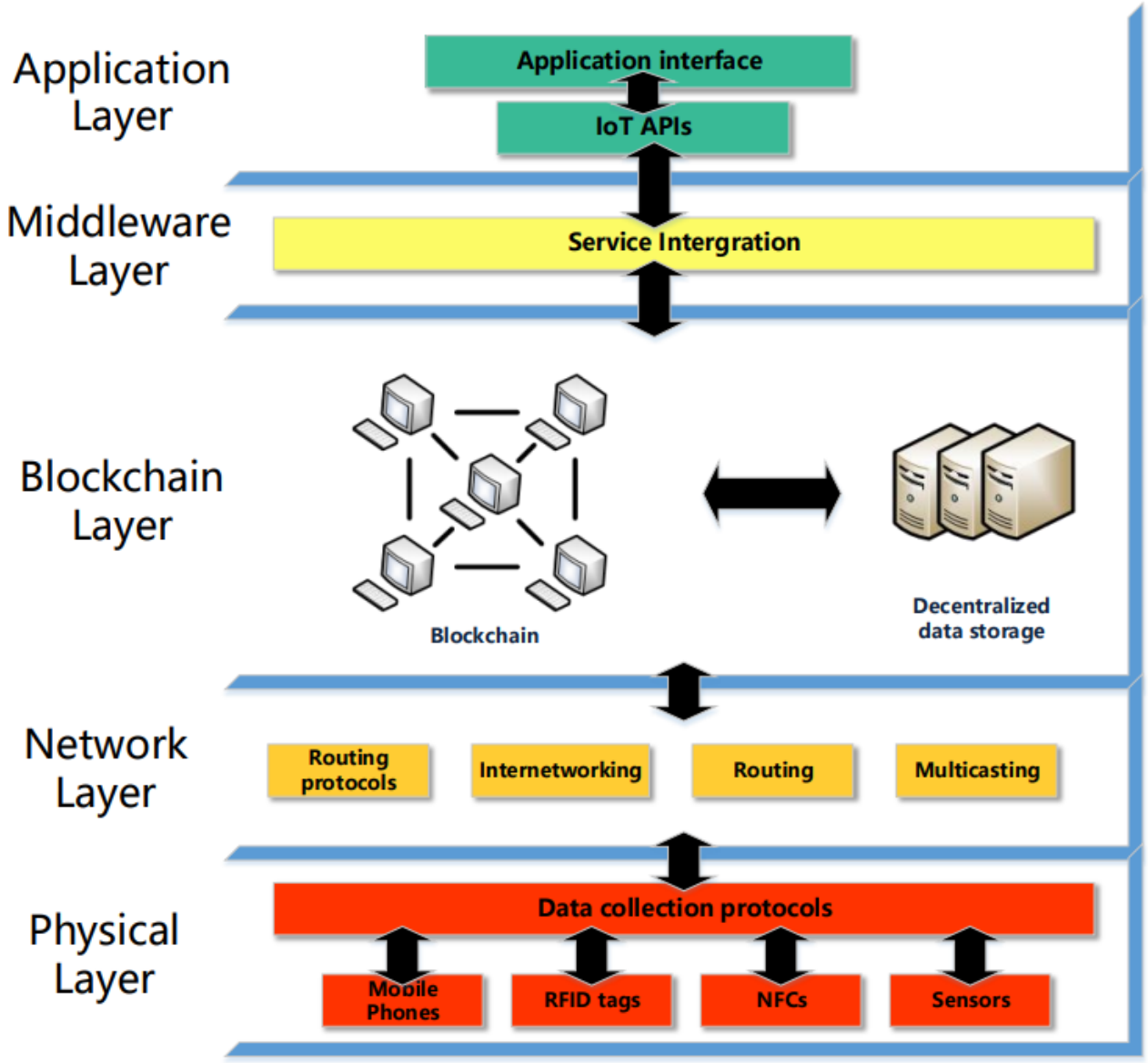
Architecture

- Summary of IoT-Blockchain Architectures

IoT Blockchain	Application Layer	Middleware Layer	Blockchain Layer	Network Layer	Physical Layer
Smart home	Smart home application	Overlay blockchain management	Commercial blockchain	P2P network	Smart device
LO3 Energy	Energy shopping application	Exergy token system	Public blockchain solution	low latency network	Grid Edge, Solar plane
Slock.it	DApp	None	Ethereum	Commercial network	Electronic locks
Hybrid-IoT	IoT application	Hybrid-IoT platform	PoW blockchain, BFT blockchain	P2P network	Full peer, Light peer, Sensor
BPIIoT	Manufacturing DApps	Single-board computers	Blockchain network bridge	P2P network	Industrial IoT device
JD.COM	JD.com	Blockchain gateway service	BFT blockchain	P2P network	IoT devices
IoT data Service Framework	Data user application	Data integrity service framework	Ethereum	P2P network	IoT devices
IoTChain	Authorized access	OSCAR, ACE framework	Ethereum	Commercial network	IoT devices

Architecture

- Proposed general IoT-blockchain architecture



Consensus

- Helps multiple participants in a network to reach a necessary agreement
- Fault-tolerant in providing reliable services
- Set of rules to maintain a synchronized state
  - Efficiency
  - Cost-effectiveness
  - High performance.

Consensus

- Byzantine Fault Tolerance Series
  - PBFT
  - HQ replication
  - SBFT
  - RBFT
- Proof-of-Somethings (PoX) Series
  - PoW, PoS, PoC, PoA, PoI, PoB
- DAG Series
- Ripple Series

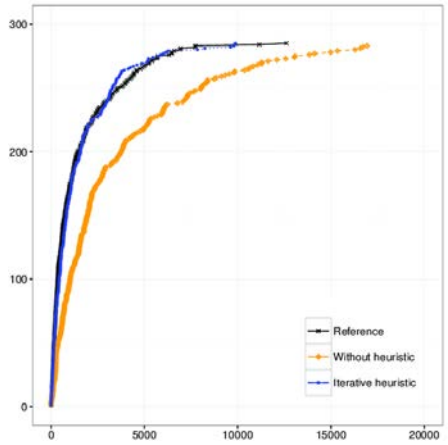
Consensus

- Small scale network – BFT consensus
- Public chain – PoX mechanism
- DAG - high efficiency, low computational overhead, high throughput, early stage

Name	Type	Throughput	Scalability	Finality	Adversary Tolerance	Advantage	Disadvantage	Vulnerability	Application
BFT	Permissioned	High	Low	Deterministic	33.3% Replicas	Low Transaction Cost Instant Block Finality	Communication Overhead Centralization	33% Attack	Tendermint
PBFT	Permissioned	High	Low	Deterministic	33.3% Faulty Replicas	High Throughput Instant Block Finality	Communication Overhead Centralization	33% Attack	Hyperledger
PoW	Permissionless	Low	Low	Probabilistic	50% Computing Power	Free to Join Adaptive Consensus	Low Throughput Waste Energy High Fork Rate	Selfish Mining	Bitcoin
PoS	Permissionless	Low	Low	Probabilistic	50% Stake	Energy Efficient Rolling Committee	Communication Overhead Matthew Effect	Long Range Attack	Peercoin
PoC	Permissionless	Low	Low	Probabilistic	50% Space	Energy Efficient	Waste Disk Space	Selfish Mining	IPFS
PoA	Permissionless	Low	High	Probabilistic	50% of Online Stake	Energy Efficient	Trust Requirement Limited Application Scenarios	Single Point Failure	Decred
PoI	Permissionless	Low	Low	Probabilistic	50% Stake	Less Chance of Hoarding	Trust Requirement	Single Point Failure	NEM
PoB	Permissionless	Low	Low	Probabilistic	50% Coins	Long-Term Incentive	Low Confirmation Latency	Denial-of-Speding Attack	XCP
DAG	Permissioned	High	High	Probabilistic	33.3% Computing Power	High Throughput	Communication Overhead	Sybil Attack	IOTA
Ripple	Permissionless	High	High	Deterministic	20% Faulty Nodes	Energy Efficient Fast Block Finality	Trust Requirement	Single Point Failure	Ripple

Traffic Model

- Carried out from the Internet to IoT networks in many research
- Blockchain traffic models
  - Peer-to-peer (P2P) traffic models
    - Message exchange
    - Message validation
    - Transaction process
- No IoT-blockchain traffic models



Traffic Model

- P2P network modeling

$$p(i) = \frac{K}{(i+q)^{\alpha}},$$

- Gossip network modeling

$$\sum_{N_p \in g} I(N_p)(\sum_{N_a} S(N_p)).$$

$$\sum_{N_p \in g} S(N_p)(\sum_{N_q} I(N_p)).$$

- Kademlia network modeling

$$\sup_{x_1,\ldots,x_n} \sup_{x \in \{x_1,\ldots,x_n\}} \sup_{y \in \{0,1\}^d} \mathbb{E}[T_{xy}] \leq (1 + o(1)) \frac{\log n}{H_k}.$$

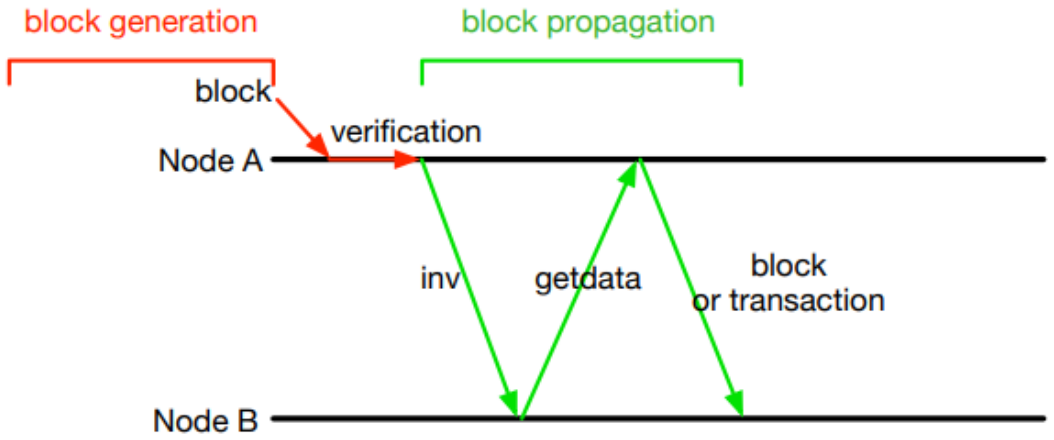
Traffic Model

- Block generation
  - Proof-of-Work
  - Mining difficulty increases over time as the global computing power of miners increase
  - A block is produced in every 10 minutes

$$P_g = \int_0^\infty \frac{(\lambda_b t_c)^N}{N!} e^{-\lambda_b t_c} dt_c.$$

- Block propagation
  - Blocks
  - Transactions

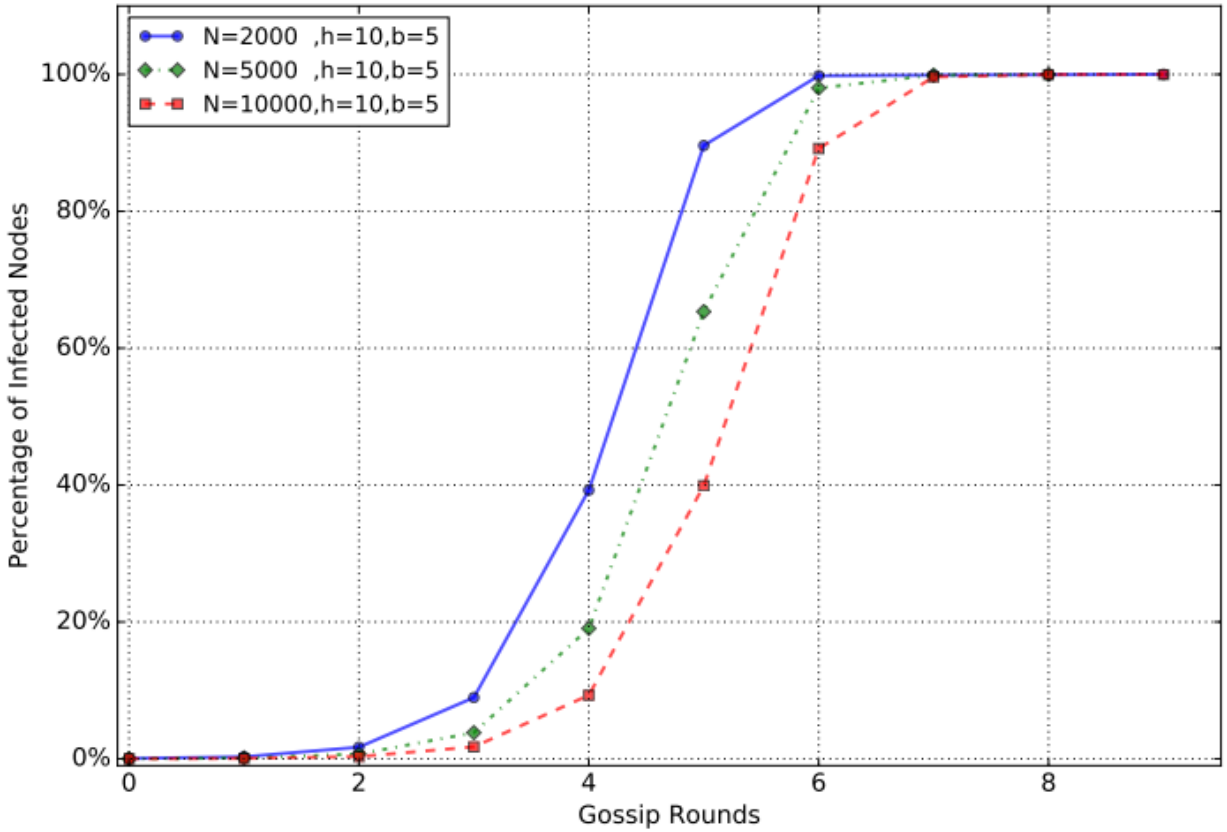
$$\frac{A_g L_b}{R_b} T_p.$$



Traffic Model

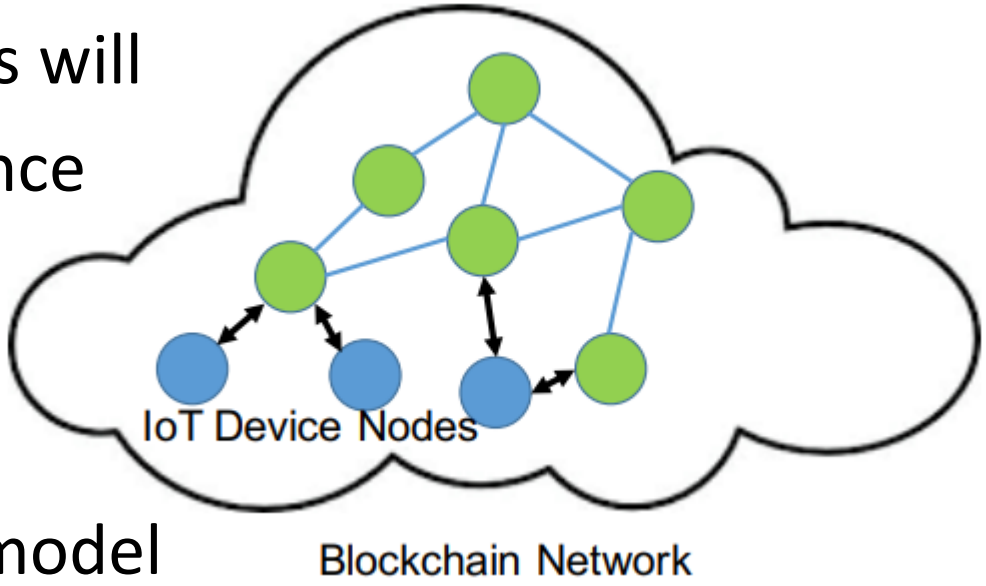
- Our simulation
  - 2000, 5000, and 10000 nodes
  - Seven gossip rounds

$$TRFC(T) = \frac{(n+1)S_{msg}}{1 + ne^{-\beta(n+1)T}}.$$



Traffic Model

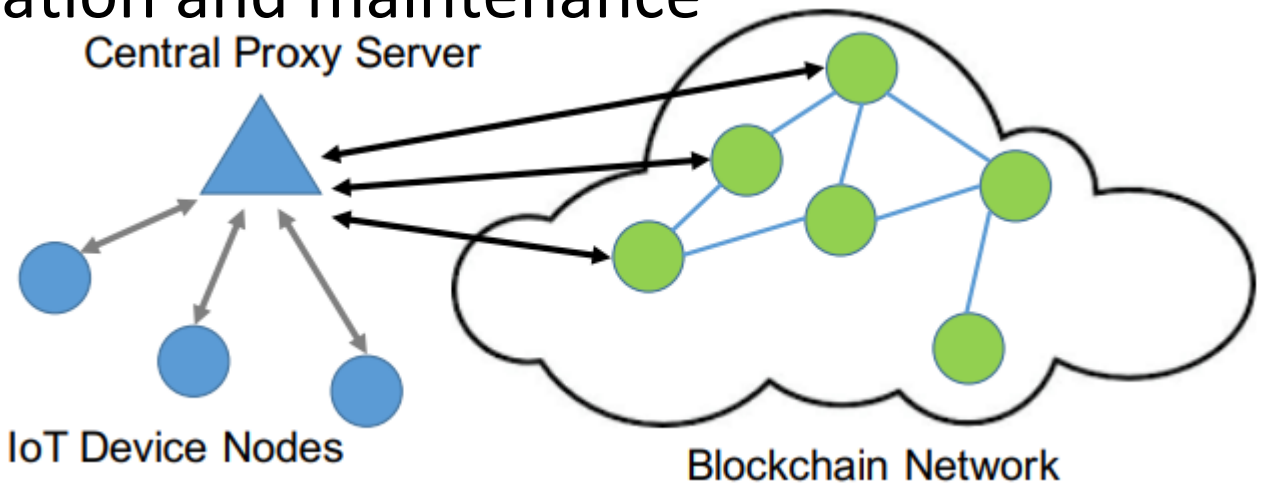
- IoT Devices in the Blockchain Network Structure
  - IoT device nodes are considered as light nodes
  - Blockchain nodes as backbone
  - Failure of IoT nodes will not affect performance



Traffic follow our traffic model

Traffic Model

- IoT Devices Outside of the Blockchain Network Structure
  - Proxy server act as traffic regulator
  - IoT nodes not directly connected to the blockchain network
  - Easy configuration and maintenance



Conclusion

- Blockchain provided practical solution to IoT applications
- This paper presents a comprehensive overview of IoT blockchains
  - Typical architectures
  - Consensus mechanism
  - Traffic models
- Future research directions

Thank You!!!