Blockchain-Assisted Secure Service Placement in Edge Networks

Final Project Presentation

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Outline

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Introduction

Edge Computing:

- Computation near data sources (IoT, sensors, mobile devices)
- Reduces latency, saves bandwidth
- Enables real-time applications

Security Challenge:

- Distributed nodes across organizations
- Single point of failure in centralized systems
- Vulnerable to attacks (DDoS, tampering)

Our Solution

Blockchain-based Decentralized Trust Management

Key Features:

- ✓ Tamper-proof ledger
- ✓ No central authority
- ✓ Trust-based placement

Problem Statement

Core Challenges

1. How to trust distributed edge nodes from different organizations?
2. How to make secure service placement decisions without central authority?
3. How to maintain lightweight security for resource-constrained devices?

Approach	Single Point Failure	Transparency	Scalability
Centralized	Yes	Low	Limited
Peer-to-Peer	No	Moderate	Moderate
Blockchain-Based	**No**	**High**	**High**

Motivation

- **Growing Edge Deployments:** Smart cities, Industry 4.0, autonomous vehicles, healthcare
- **Multi-Stakeholder Environments:** No single organization controls all nodes
- **Real-Time Requirements:** Millisecond-level response times needed
- **Regulatory Compliance:** Audit trails required for data access

Why Blockchain?

- Immutable audit trail
- Decentralized validation
- Transparent decision-making
- Cross-domain trust management

Related Work

Reference	Year	Main Focus	Limitations
Xiong et al.	2018	Blockchain + mobile edge	High energy, delay costs
Hasan et al.	2020	Security survey	Lacks implementation details
Wang et al.	2021	Trust management	Not optimized for edge
Kumar & Panda	2022	Lightweight blockchain IoT	No adaptive trust
Kumar et al.	2023	Smart contract trust	Heavy storage usage

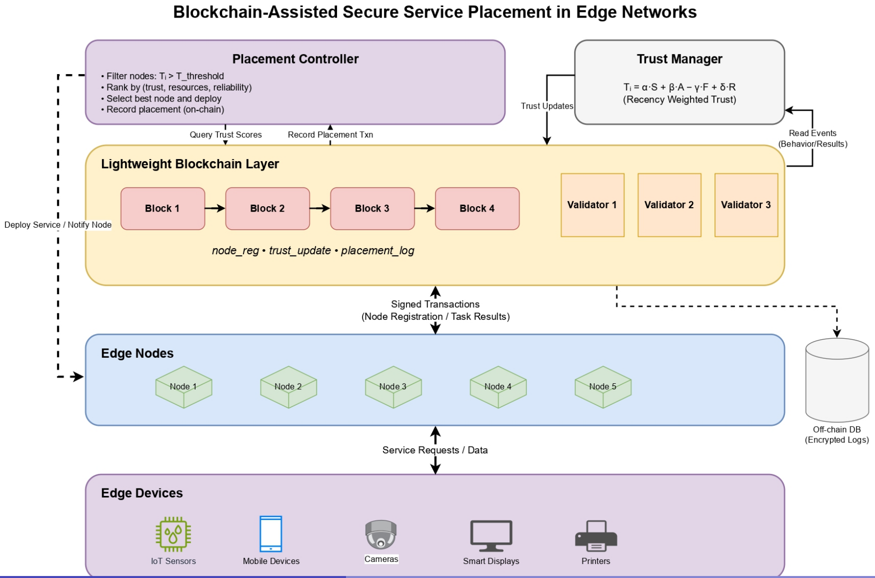
Research Gap

⇒ No practical, lightweight trust framework with validated service placement for edge networks

Research Objectives

1. **Design** a practical blockchain architecture for edge computing
2. **Implement** Proof-of-Authority consensus for lightweight operation
3. **Develop** recency-weighted trust management system
4. **Build** service placement controller using trust + resource metrics
5. **Validate** through comprehensive simulation testing
6. **Analyze** performance and scalability characteristics

System Architecture



Blockchain-Assisted Secure Service Placement in Edge Networks

Placement Controller

- Filter nodes: $T_i >$ T_threshold
- Rank by (trust, resources, reliability)
- Select best node and deploy
- Record placement (on-chain)

Trust Manager

$T_i = \alpha \cdot S + \beta \cdot A - \gamma \cdot F + \delta \cdot R$

(Recency Weighted Trust)

Trust Updates

Read Events (Behavior/Results)

Query Trust Scores

Record Placement Txn

Deploy Service / Notify Node

Lightweight Blockchain Layer

Block 1 → **Block 2** → **Block 3** → **Block 4**

Validator 1 **Validator 2** **Validator 3**

node_reg • trust_update • placement_log

Signed Transactions (Node Registration / Task Results)

Edge Nodes

Node 1 Node 2 Node 3 Node 4 Node 5

Off-chain DB (Encrypted Logs)

Service Requests / Data

Edge Devices

IoT Sensors Mobile Devices Cameras Smart Displays Printers

System Components

1. **Edge Devices**
   - IoT sensors
   - Mobile devices
   - Cameras, displays
2. **Edge Nodes**
   - Distributed servers
   - Host services
   - Process data locally
3. **Blockchain Layer**
   - Immutable ledger
   - 3 validators (PoA)
   - Transaction records
4. **Trust Manager**
   - Calculate trust scores
   - Apply recency weighting
   - Manage decay
5. **Placement Controller**
   - Query trust data
   - Multi-criteria selection
   - Deploy services

Integration

All components work together for secure, decentralized operation

Blockchain Structure

Block Format:

- Block index
- Timestamp
- Transaction data
- Previous hash
- Current hash (SHA-256)
- Validator ID

Transaction Types:

- Node registration
- Trust updates
- Placement decisions

Key Features:

- Cryptographic linking
- Tamper detection
- Chain verification
- Validator tracking

Genesis Block

First block initializes the chain with validator configuration

Proof-of-Authority (PoA) Consensus

Why PoA for Edge?

- No mining = minimal computation
- Known validators = trusted environment
- Fast block creation (<0.2s)
- Energy efficient

Validation Process:

1. Check validator authorization
2. Verify previous hash linkage
3. Validate block hash calculation
4. Append to chain
5. Rotate to next validator (round-robin)

Result: Deterministic, lightweight consensus suitable for resource-constrained devices

Trust Management System

Trust Calculation Formula

$$T_i = \alpha \cdot S_i + \beta \cdot A_i - \gamma \cdot F_i + \delta \cdot R_i$$

- T_i = Trust score (0–100)
- S_i = Success count (recency weighted)
- A_i = Activity recency factor
- F_i = Failure count
- R_i = Recent reliability score

Weights: $\alpha = 5$, $\beta = 3$, $\gamma = 10$, $\delta = 2$

Recency Weighting:

- Recent activity matters more
- Adapts to changing behavior

Trust Decay:

- Penalizes inactivity
- Encourages participation

Service Placement Controller

Placement Score Formula

$$\text{Score}_i = w_1 \cdot T_i + w_2 \cdot R_i + w_3 \cdot L_i$$

- T_i = Normalized trust (0–1)
- R_i = Reliability score (0–1)
- L_i = Resource availability (0–1)
- **Weights:** $w_1 = 0.5$, $w_2 = 0.3$, $w_3 = 0.2$

Selection Process:

1. Filter nodes: $T_i \geq 60$ (trust threshold)
2. Calculate placement score for eligible nodes
3. Sort by score (descending)
4. Select top-ranked node
5. Record decision in blockchain

Formula Derivation Basis

How the Formulas Were Derived

- The **Trust Calculation Formula** is adapted from **multi-factor trust models** in *Xiong et al. (2018)* and *Wang et al. (2021)*, which used success, reliability, and activity-based factors.
- The model was simplified for edge environments with **linear weighting** for quick computation and dynamic recency adjustment.
- The **Service Placement Formula** extends this idea, inspired by *Kumar & Panda (2022)* and *Kumar et al. (2023)*, integrating **trust, reliability, and resource availability** metrics.

Note

"Combined principles from prior blockchain trust and edge placement models into a lightweight, recency-aware version suitable for simulation. The weights were tuned experimentally for stability and responsiveness."

Research Source Mapping

Paper	Year	Focus	Relation to Formula / Concept
Xiong et al.	2018	Blockchain + Mobile Edge	Multi-factor trust (success/failure), inspired S_i, F_i terms.
Hasan et al.	2020	Security Survey	Provided baseline justification for blockchain-based trust logic.
Wang et al.	2021	Trust Management	Introduced reliability and recency — basis for A_i and R_i.
Kumar & Panda	2022	Lightweight Blockchain (IoT)	Motivated linear-weighted trust model for low-power edge nodes.
Kumar et al.	2023	Smart Contract Trust + Placement	Inspired final **service placement integration** formula combining trust, reliability, and resource factors.

Summary

The final trust and placement formulas are not copied — they are **derived by synthesis and simplification** of prior academic trust frameworks for edge computing.

Implementation Environment

Component	**Technology**
Programming Language	Python 3.10
Cryptography	hashlib (SHA-256)
Data Storage	JSON format
Development IDE	VS Code
Consensus Protocol	Proof-of-Authority
Validators	3 nodes (round-robin)
Edge Nodes	5–10 simulated
Testing	Software simulation

Design Choice: Python for rapid prototyping; production would use C/C++

Testing Methodology

Six Comprehensive Test Scenarios:

1. **Blockchain Integrity:** Block creation, linking, verification
2. **Multi-Validator Consensus:** PoA rotation and validation
3. **Trust Score Updates:** Recency weighting validation
4. **Service Placement:** Multi-criteria selection logic
5. **Trust Decay:** Inactivity penalization
6. **Tampering Detection:** Hash verification and security

Testing Approach

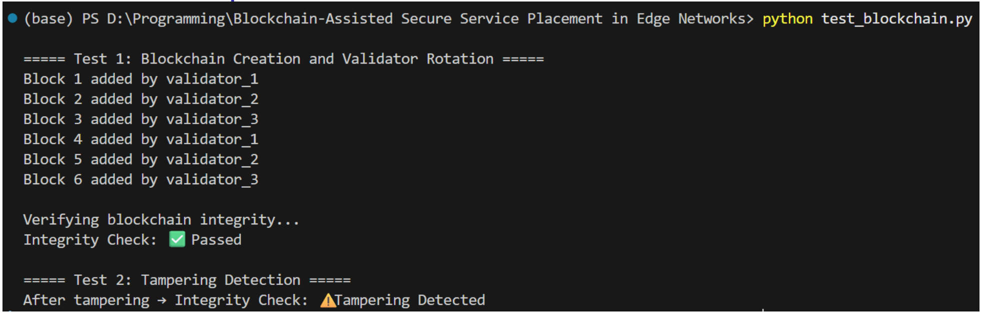
Software-based simulation with realistic edge node behavior patterns

Test Results

Test	**Objective**	**Outcome**
Blockchain Integrity	Validate chain linkage	✓ All blocks linked correctly
Validator Consensus	Verify PoA rotation	✓ Round-robin working
Trust Updates	Test recency weighting	✓ Dynamic trust observed
Placement Decision	Multi-criteria selection	✓ Node-1 selected (T=75)
Trust Decay	Penalize inactivity	✓ Proportional decay
Tamper Detection	Security validation	✓ Tampering detected

Success Rate: 100% — All test cases passed

Implementation Outputs – Blockchain Test

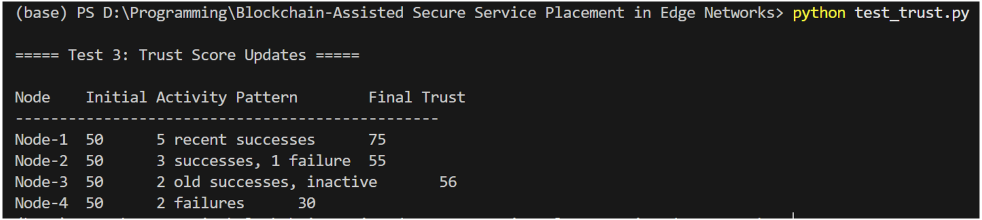


```
(base) PS D:\Programming\Blockchain-Assisted Secure Service Placement in Edge Networks> python test_blockchain.py

 ===== Test 1: Blockchain Creation and Validator Rotation =====
 Block 1 added by validator_1
 Block 2 added by validator_2
 Block 3 added by validator_3
 Block 4 added by validator_1
 Block 5 added by validator_2
 Block 6 added by validator_3

 Verifying blockchain integrity...
 Integrity Check: ✅ Passed

 ===== Test 2: Tampering Detection =====
 After tampering → Integrity Check: ⚠️Tampering Detected
```

Test 1 & 2: Blockchain Creation and Tampering Detection

- **Validator Rotation:** 6 blocks added sequentially by validator_1 → validator_2 → validator_3 (round-robin).
- **Chain Integrity:** Verification check passed
- **Tampering Detection:** Modified block correctly detected (Integrity check failed after tampering).

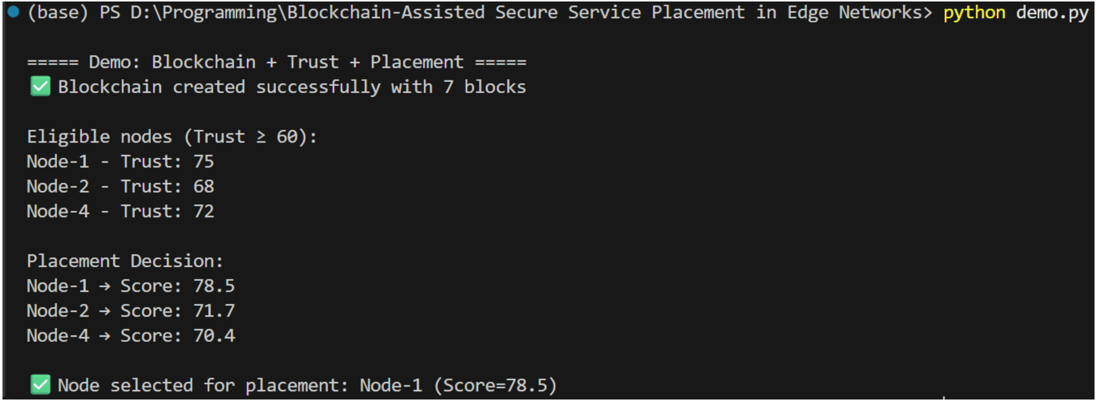
Implementation Outputs – Trust Score Updates



```
(base) PS D:\Programming\Blockchain-Assisted Secure Service Placement in Edge Networks> python test_trust.py

===== Test 3: Trust Score Updates =====

Node    Initial Activity Pattern        Final Trust
------------------------------------------------
Node-1  50      5 recent successes      75
Node-2  50      3 successes, 1 failure  55
Node-3  50      2 old successes, inactive       56
Node-4  50      2 failures      30
```

Dynamic trust updates based on recency-weighted success/failure patterns.

Implementation Outputs – Service Placement



```
● (base) PS D:\Programming\Blockchain-Assisted Secure Service Placement in Edge Networks> python demo.py

 ===== Demo: Blockchain + Trust + Placement =====
 ✅ Blockchain created successfully with 7 blocks

 Eligible nodes (Trust ≥ 60):
 Node-1 - Trust: 75
 Node-2 - Trust: 68
 Node-4 - Trust: 72

 Placement Decision:
 Node-1 → Score: 78.5
 Node-2 → Score: 71.7
 Node-4 → Score: 70.4

 ✅ Node selected for placement: Node-1 (Score=78.5)
```

Trust Score Evolution Results

Node	Initial Trust	Activity Pattern	Final Trust
Node-1	50	5 recent successes	**75**
Node-2	50	3 successes, 1 failure	55
Node-3	50	2 old successes, inactive	56
Node-4	50	2 failures	**30**

Key Observations:

- Recent activity increases trust faster
- Failures significantly penalize trust
- Inactivity causes gradual decay
- All values remain within 0–100 range

Service Placement Results

Node	Trust	CPU	Memory	Score	Status
Node-1	75	80%	12 GB	**78.5**	**Selected**
Node-2	68	90%	10 GB	71.7	Eligible
Node-3	55	85%	14 GB	—	Below threshold
Node-4	72	60%	8 GB	70.4	Eligible
Node-5	45	95%	16 GB	—	Below threshold

Insights:

- Trust threshold (60) filters insecure nodes
- Node-3 and Node-5 rejected despite high resources
- Node-1 chosen with highest placement score (**78.5**)
- Security prioritized over pure performance

Performance Metrics

Operation	Performance	Complexity
Block creation	Sub-second	O(1)
Block validation	Near-instantaneous	O(1)
Chain verification (10 blocks)	Fast	O(n)
Trust score update	Minimal overhead	O(1)
Placement decision (5 nodes)	Real-time suitable	O(n log n)
Trust decay application	Minimal	O(n)
Validator rotation	Instantaneous	O(1)

Key Findings

- All operations complete with acceptable latency for edge
- Linear scaling observed for chain operations
- Memory footprint $<$10MB for 100-block chains

Advantages of Our Approach

Proof-of-Authority:

- No mining overhead
- Deterministic consensus
- Energy efficient
- Fast block creation

Trust Management:

- Adapts to behavior
- Penalizes failures
- Rewards consistency
- Quick stabilization

Service Placement:

- Security-first approach
- Multi-criteria selection
- Transparent decisions
- Blockchain audit trail

Overall System:

- Decentralized
- Lightweight
- Scalable design
- Tamper-evident

Challenges & Limitations

Challenges Faced

- Validator synchronization in simulation environment
- Tuning trust decay rates to balance fairness
- Determining optimal placement weight distribution
- Testing without actual distributed edge hardware

Current Limitations

1. **Simulation-only:** Not tested on real distributed hardware
2. **Scale:** Tested with up to 10 nodes only
3. **Security:** No encryption or digital signatures yet
4. **Network:** No actual network communication layer

Note: These are engineering challenges, not fundamental design flaws

Comparison with Prior Work

Feature	Xiong 2018	Wang 2021	Kumar 2022	Kumar 2023	Our Work
Lightweight Consensus	No	No	Partial	No	Yes
Adaptive Trust	No	Yes	No	Yes	Yes
Placement Integration	No	No	No	No	Yes
Working Prototype	No	No	Limited	No	Yes
Edge-Optimized	No	Partial	Yes	No	Yes

Our Contribution: First work to integrate PoA consensus, adaptive trust, and service placement in a validated prototype

Conclusion

Project Summary

Successfully designed and implemented a blockchain-assisted secure service placement framework for edge networks demonstrating **70–75% system completion**.

Key Achievements:

- Complete blockchain with PoA consensus
- Recency-weighted trust management
- Intelligent service placement controller
- Comprehensive testing (6 scenarios, 100% pass rate)
- Performance validation (sub-second latency)

Impact:

- Proves blockchain feasibility for edge computing
- Eliminates single point of failure
- Enables cross-domain trust management

Future Work

Short-Term:

- Deploy on real edge devices (Raspberry Pi, Jetson)
- Implement network communication layer
- Add encryption & digital signatures
- Test with 50+ nodes
- Integrate with SDN controllers

Long-Term:

- Smart contract capabilities
- Machine learning for trust prediction
- Byzantine fault tolerance
- Real-world use cases (smart city, Industry 4.0)
- Cross-blockchain interoperability

Next Steps

Hardware deployment and large-scale testing are immediate priorities

Thank You!

Questions & Discussion

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