CREATION OF A RELIABLE DATA NETWORK EXCHANGE SYSTEM USING BLOCKCHAIN TECHNOLOGY

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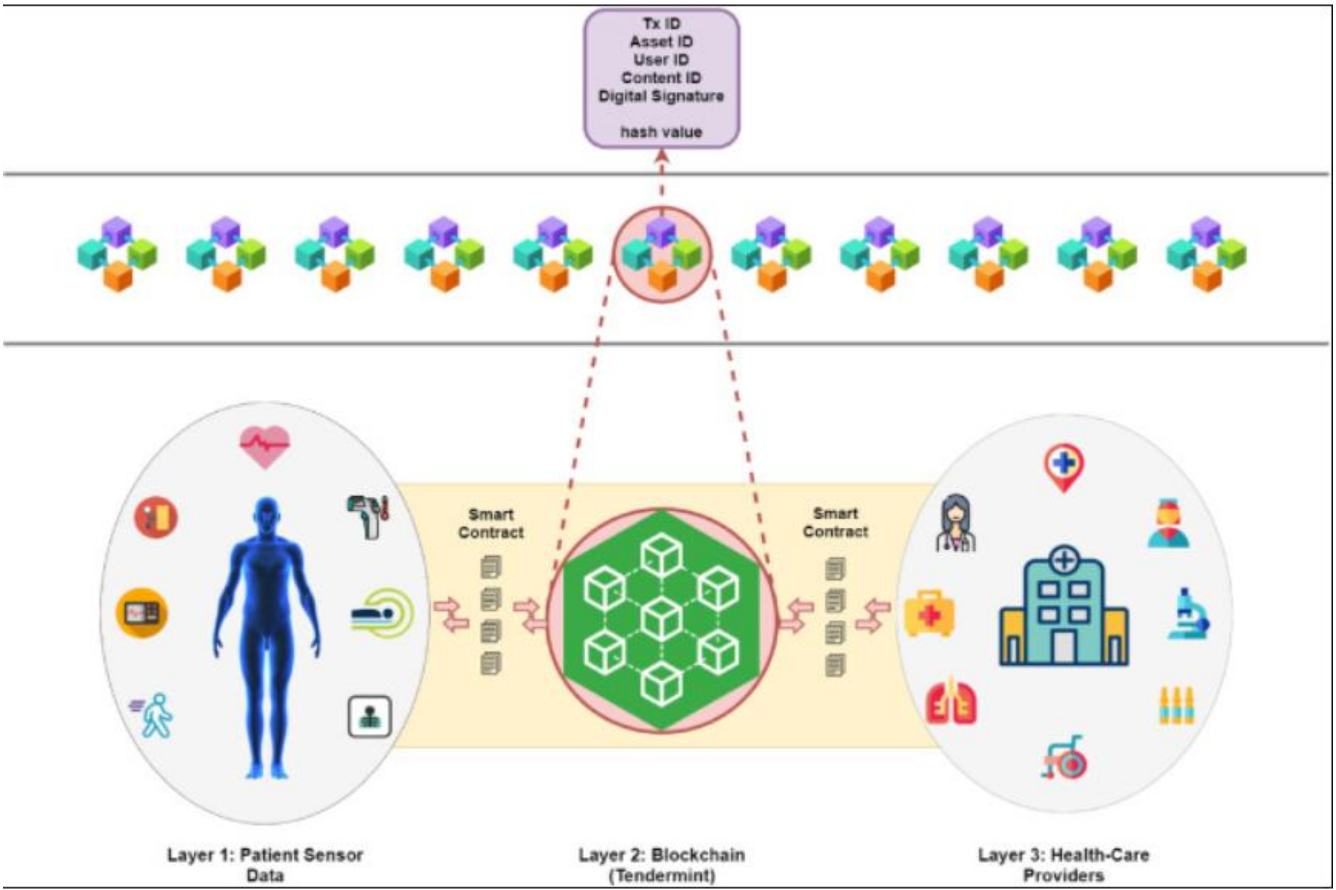
Abstract: A cyber-physical system is considered to be a collection of strongly coupled communication systems and devices that poses numerous security trials in various industrial applications including healthcare. The security and privacy of patient data is still a big concern because healthcare data is sensitive and valuable, and it is most targeted over the internet. Moreover, from the industrial perspective, the cyber-physical system plays a crucial role in the exchange of data remotely using sensor nodes in distributed environments. In the healthcare industry, Blockchain technology offers a promising solution to resolve most securities-related issues due to its decentralized, immutability, and transparency properties. In this paper, a blockchain-inspired secure and reliable data exchange architecture is proposed in the cyber-physical healthcare industry 4.0. The proposed system uses the BigchainDB, Tendermint, Inter-Planetary-File-System (IPFS), MongoDB, and AES encryption algorithms to improve Healthcare 4.0. Furthermore, blockchain-enabled secure healthcare architecture for accessing and managing the records between Doctors and Patients is introduced. The development of a blockchain-based Electronic Healthcare Record (EHR) exchange system is purely patient-centric, which means the entire control of data is in the owner's hand which is backed by blockchain for security and privacy. Our experimental results reveal that the proposed architecture is robust to handle more security attacks and can recover the data if 2/3 of nodes are failed. The proposed model is patient-centric, and control of data is in the patient's hand to enhance security and privacy, even system administrators can't access data without user permission.

Keywords: Cyber-physical system,Blockchain security , Healthcare 4.0, Electronic health records , BigchainDB, Data privacy.

We have proposed blockchain-enabled secure architecture for the healthcare system that is patient-centric and used for creating a permission-based EHR sharing system. The aim of the proposed architecture is to provide a platform that is free from modern types of attack. The proposed architecture shown in demonstrates the deployment of blockchain technology for exchanging EHR in three levels. Different IoT sensors have been used to collect health-related data like Heart Rate, Blood Pressor, Motion Sensor, etc., which is attached to the Patient's body for various purposes like real-time monitoring of heart rate, and oxygen saturation level for enhanced treatment. Some of these are implanted devices that have resource constraints especially unable to perform computation. Hence, an emerging computing paradigm named edge devices are used to send the data or process a limited amount of time-sensitive data. The data is stored, shared, and updates by the entities of healthcare personnel in the blockchain networks. This is a medical software application that allows doctors and patients to transmit and receive health information or services from distant locations using blockchain technology. The proposed blockchain-enabled architecture ensures the privacy and security of patient data.



Core Problem: Most of today's data exchange frameworks operate in centralized infrastructures, which inherently create a single point of failure. Centralized servers can be breached, manipulated, or incapacitated by Distributed Denial of Service (DDoS) attacks. Additionally, centralized authorities control and monetize data access, often without full transparency to the user. This results in a trust deficit between data providers and data consumers.

Proposed Solution: Blockchain-Based Distributed Data Exchange

Blockchain technology, with its decentralized and tamper-proof ledger system, presents a transformative solution to these challenges. It enables the creation of a **reliable, secure, and transparent data exchange network** by distributing control across numerous nodes and employing cryptographic validation for each data transaction.

A blockchain-based system ensures that:

- **Data cannot be altered retroactively** without consensus from the network.
- **Every transaction is recorded and auditable.**
- **Redundancy and fault-tolerance** are inherently built into the architecture.
- **Trustless interactions** become possible via smart contracts and distributed consensus.

Blockchain thus allows the construction of **peer-to-peer (P2P) data marketplaces**, decentralized healthcare record systems, and tamper-proof IoT communication networks.

How Blockchain Works: Technical Principles

A blockchain is a **chain of blocks**, where each block contains:

- A timestamp
- A list of transactions (data records)
- A reference (hash) to the previous block
- A cryptographic nonce for proof-of-work (PoW) or signature for proof-of-stake (PoS)

Each block is validated through a **consensus mechanism**, such as:

- **Proof of Work (PoW):** Nodes compete to solve complex math puzzles to validate transactions.
- **Proof of Stake (PoS):** Validation rights are assigned based on the stakeholder's ownership.
- **Delegated PoS / Practical Byzantine Fault Tolerance (PBFT):** Used in private or consortium blockchains.

Hash Function:

A key cryptographic element of blockchain is the **hash function**: Where is input data and is the fixed-length hash. Common algorithms include SHA-256 and Keccak256.

Data Integrity and Merkle Trees

In blockchains, data integrity is maintained using **Merkle Trees**, where every transaction is hashed, and the hashes are combined pairwise up to a single root hash.

Merkle Root Formula:

This enables quick verification of whether a transaction belongs to a block without downloading the entire dataset.

Use cases:

- Verifying whether a medical record exists without seeing full details.
- Confirming that sensor data has not been tampered with.

Application Example: Secure Healthcare Data Exchange

Case Study Problem: Multiple hospitals need to share patient records, but privacy, trust, and data consistency are critical.

Blockchain Solution:

- Each patient's encrypted record is stored in a decentralized ledger.
- Smart contracts manage permissions (e.g., only the doctor with access key can read data).
- Access logs are written immutably to the chain.

Result:

- Eliminates duplication of records
- Patients retain control over their data
- Prevents unauthorized access or modification

Benefits of Blockchain-Based Data Exchange Systems

1. **Decentralization** — Eliminates single points of failure and enhances resilience.
2. **Transparency** — All stakeholders can verify and audit data exchange activities.
3. **Security** — Cryptographic protection makes tampering practically impossible.
4. **Scalability** — Through Layer-2 protocols and sharding.
5. **Efficiency** — Reduces reliance on intermediaries.
6. **Smart Automation** — Using smart contracts for automatic rule enforcement.

Challenges in Real-World Implementation

Despite the advantages, deploying blockchain at scale involves challenges:

- High computational cost of PoW algorithms
- Data privacy regulation compliance (e.g., GDPR)
- Integration with legacy systems
- On-chain storage limitations (IPFS helps solve this)

Solutions:

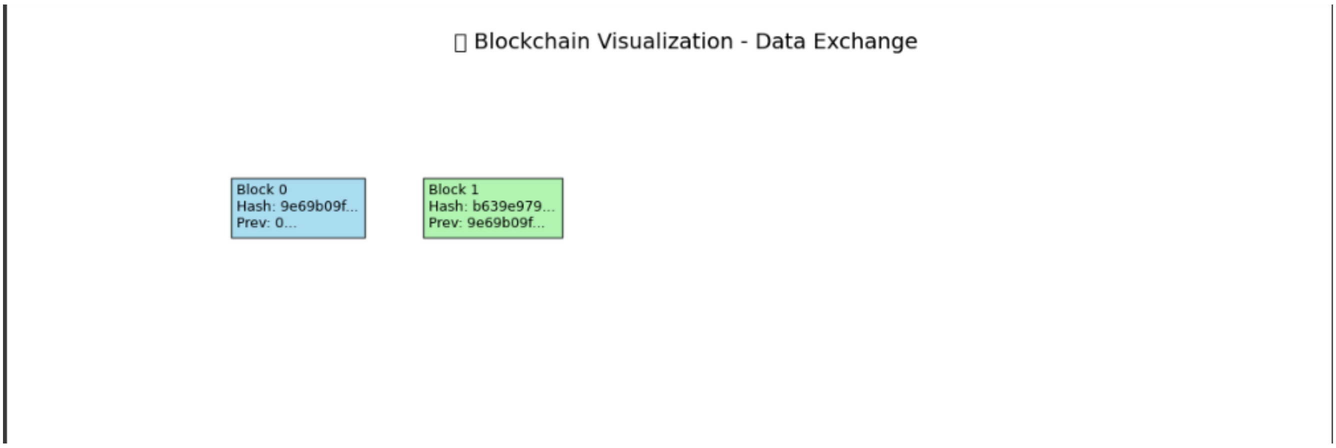
- Use PoS or PBFT for efficiency
- Encrypt sensitive data before putting it on-chain

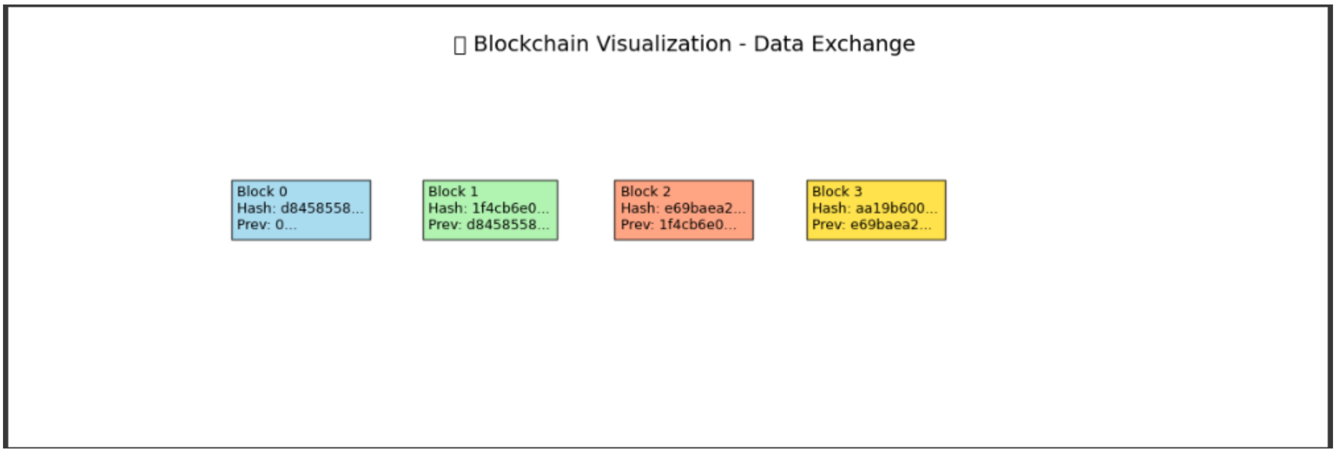
• Store large files off-chain using IPFS, and link hashes on-chain

The following Python code demonstrates a **simulation of a blockchain network**, showing how data blocks are generated, hashed, and linked. It includes animation for visualization.

```
import hashlib
import time
import matplotlib.pyplot as plt
import matplotlib.animation as animation
from IPython.display import HTML

class Block:
    def __init__(self, index, data, prev_hash):
        self.index = index
        self.timestamp = time.time()
        self.data = data
        self.prev_hash = prev_hash
        self.hash = self.calc_hash()

    def calc_hash(self):
        to_hash = str(self.index) + str(self.timestamp) + str(self.data) + str(self.prev_hash)
        return hashlib.sha256(to_hash.encode()).hexdigest()

# Create the blockchain
blockchain = [Block(0, "Genesis Block", "0")]

def add_block(data):
    prev_block = blockchain[-1]
    new_block = Block(len(blockchain), data, prev_block.hash)
    blockchain.append(new_block)

# Add some blocks
add_block("Patient A record")
add_block("Patient B record")
add_block("Doctor access request")
add_block("X-ray image link")

# Animation
fig, ax = plt.subplots(figsize=(12, 4))
```

```
colors = ['skyblue', 'lightgreen', 'coral', 'gold']

def animate(i):
    ax.clear()
    for idx, block in enumerate(blockchain[:i+1]):
        ax.text(idx*3, 0.5, f"Block {block.index}\nHash: {block.hash[:8]}...\nPrev: {block.prev_hash[:8]}...",
                bbox=dict(facecolor=colors[idx % len(colors)], alpha=0.7), fontsize=9)
    ax.set_xlim(-1, len(blockchain)*3)
    ax.axis('off')
    ax.set_title("🔗 Blockchain Visualization - Data Exchange", fontsize=14)

ani = animation.FuncAnimation(fig, animate, frames=len(blockchain), interval=2000, repeat=False)

# Display animation in Google Colab
HTML(ani.to_jshtml())
```





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