PharmaChain 3.0: Blockchain Integrated Efficient QR Code Mechanism for Pharmaceutical Supply Chain

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Outline

- Counterfeit in HealthCare
- Blockchain Technology
- PharmaChain
- PharmaChain 2.0
- PharmaChain 3.0
- Working Flow of PharmaChain 3.0
- Implementation and Validation
- Conclusions & Future Work

Counterfeit in Healthcare

Counterfeit Medicines is a Problem

Tamiflu is an antiviral drug for the treatment of the flu.

Daflon 500 used to treat gravitational (stasis) dermatitis, and dermatofibrosclerosis

- Drug Components: Active Pharmaceutical Ingredient (API) + Excipients or inactive ingredients
- Counterfeit Drugs: Less API or no API or wrong API drugs produced in sub-standard conditions

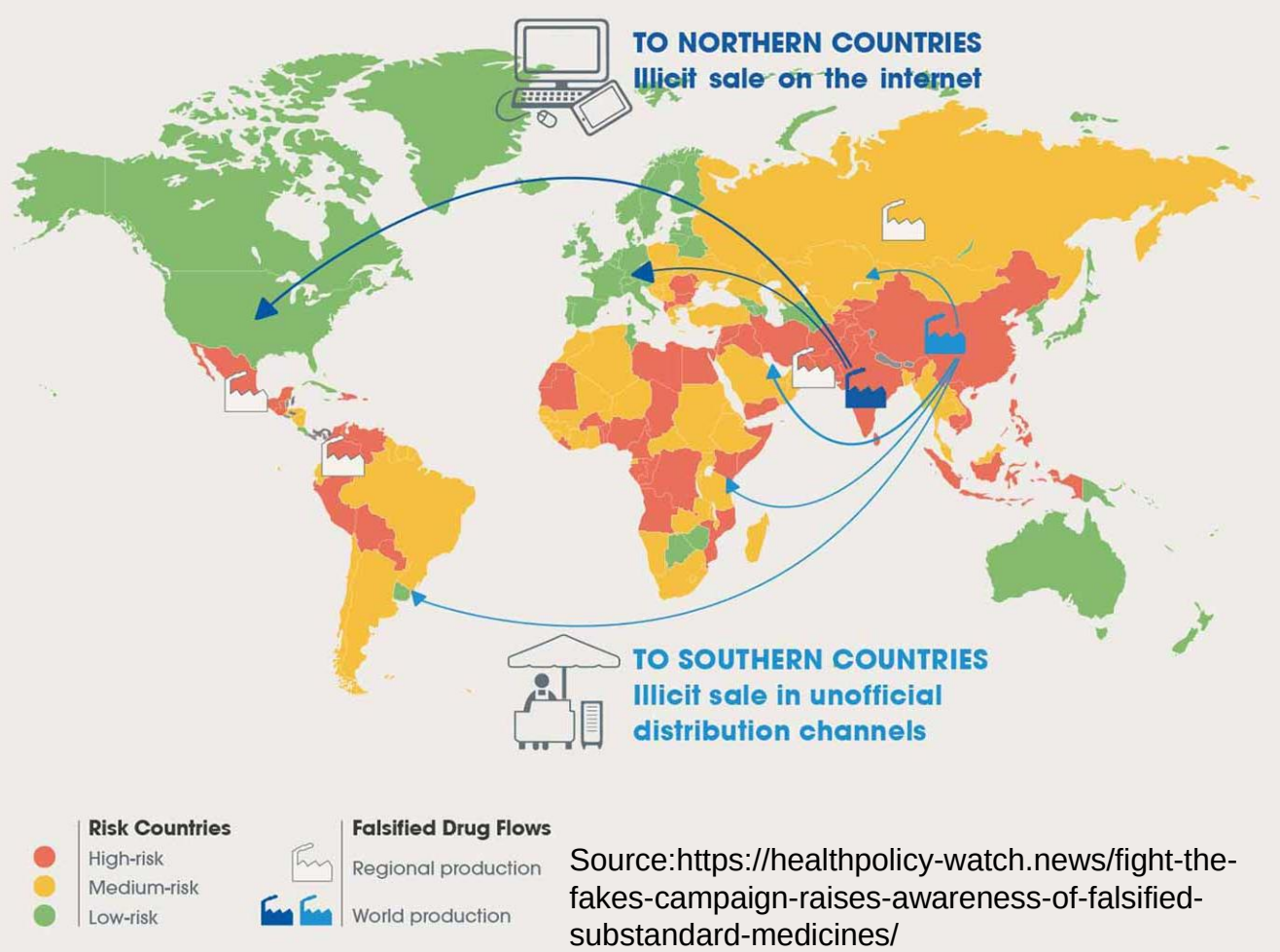
Image Source: https://www.stabroeknews.com/2019/09/06/business/ga-fdds-occasional-fake-drugs-disclosures-may-be-tip-of-the-iceberg/

Fake Medicine - Serious Global Issue

- It is estimated that close to $83 billion worth of counterfeit drugs is sold annually.
- One in 10 medical products circulating in developing countries are substandard or fake.
- In Africa: Counterfeit antimalarial drugs result in more than 120,000 deaths yearly.
- USA has a closed drug distribution system intended to prevent counterfeits from entering U.S. markets, but it isn't foolproof for many reasons, including illegal online pharmacies.

Source: https://fraud.org/fakerx/fake-drugs-and-their-risks/counterfeit-drugs-are-a-global-problem/

Source: https://allaboutpharmacovigilance.org/be-aware-of-counterfeit-medicine/



Source:https://healthpolicy-watch.news/fight-the-fakes-campaign-raises-awareness-of-falsified-substandard-medicines/

Counterfeits in Healthcare → Severe Direct Impact

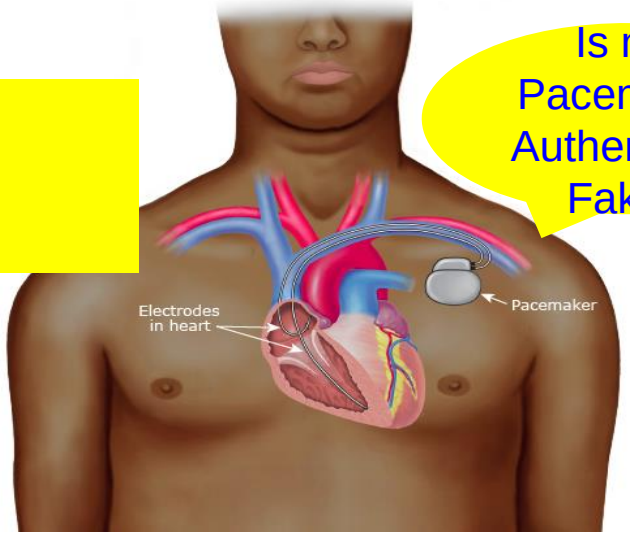
Authentic

Fake

An implantable medical device

Fake data by adversaries

- Consumers are always in dilemma
- Health Security issues



Is my Pacemaker Authentic or Fake?

Typical Pharmaceutical Supply Chain

Source: Bapatla, A.K., et al.: PharmaChain: a blockchain to ensure counterfeit-free pharmaceutical supply chain. IET Netw. 1– 24 (2022). https://doi.org/10.1049/ntw2.12041

Issues in Traditional PSC

08/22/2022

BEAUMONT, Texas – A Florida-based pharmaceutical president has pleaded guilty to federal drug trafficking violations in the Eastern District of Texas, announced U.S. Attorney Brit Featherston toda

11/12/2021

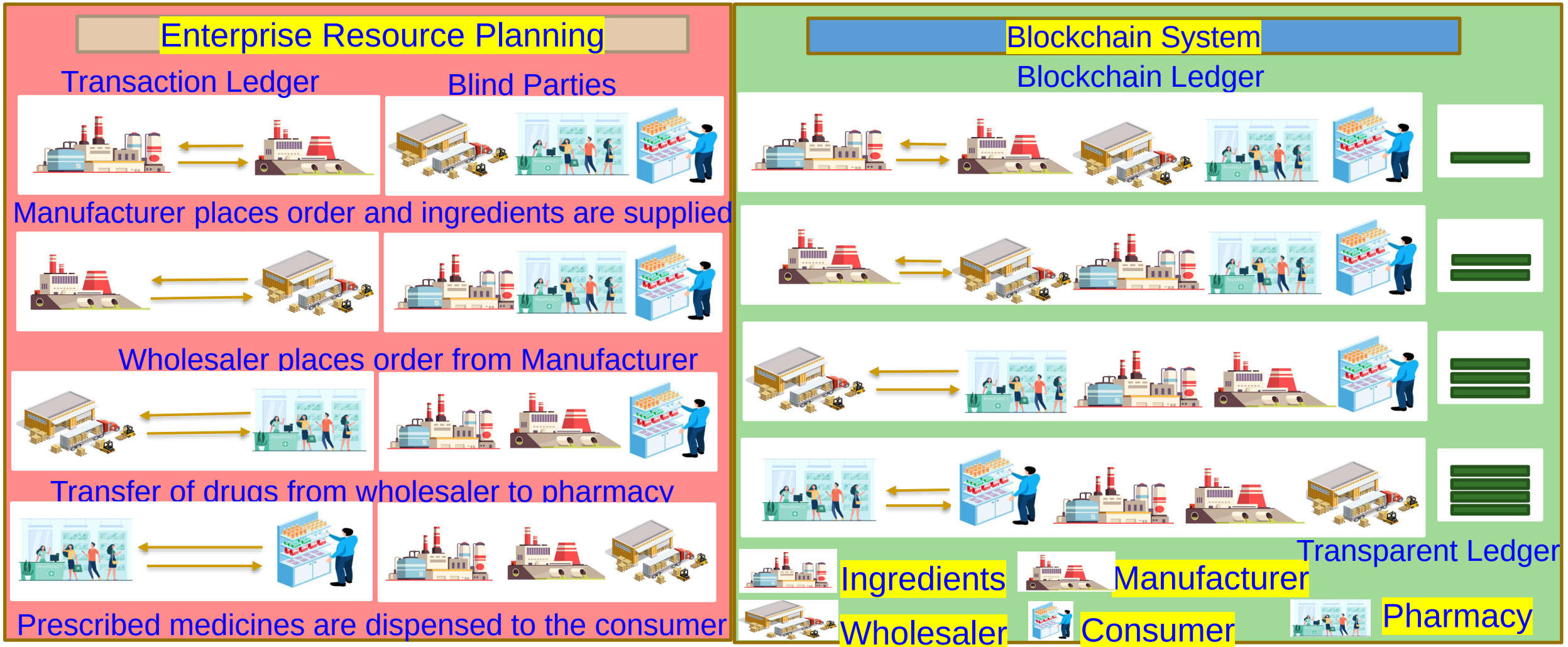
A federal grand jury in Beaumont has returned a three-count indictment charging nine individuals in drug trafficking conspiracy in the Eastern District of Texas, announced Acting U.S. Attorney Nicholas J. Ganjei today

08/24/2021

ALEX NDRIA, Va. – An Inverness, Florida, man was sentenced today to three years in prison for selling hundreds of thousands of counterfeit prescription drug pills through the Internet.

News Source: Affairs, O. of R. (n.d.). *Press releases*. U.S. Food and Drug Administration. Retrieved November 15, 2022, from https://www.fda.gov/inspections-compliance-enforcement-and-criminal-investigations/criminal-investigations/press-releases

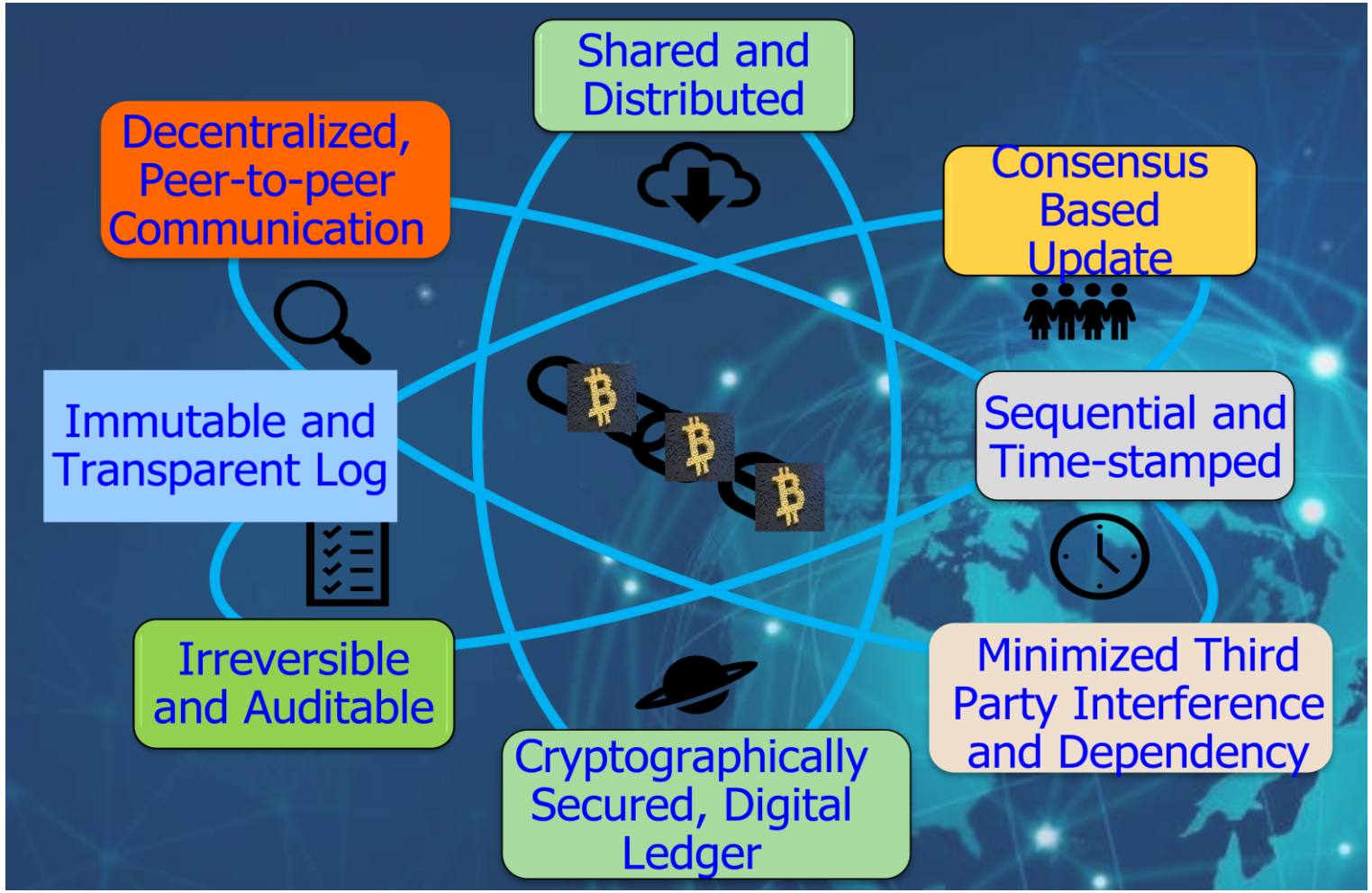
PharmaChain - Counterfeit Free Pharmaceutical



Source: A. K. Bapatla, **S. P. Mohanty**, E. Kougianos, D. Puthal, and A. Bapatla, "PharmaChain: A Blockchain to Ensure Counterfeit-Free Pharmaceutical Supply Chain", *IET Networks*, Vol. XX, No. YY, ZZ 2022, pp. Accepted on 24 June 2022, DOI: https://doi.org/10.1049/ntw2.12041. (Dataset for Research: GitHub)

Blockchain Technology

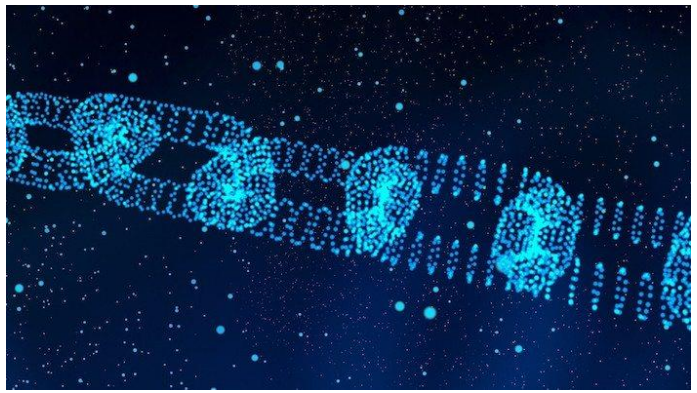
Blockchain Definition

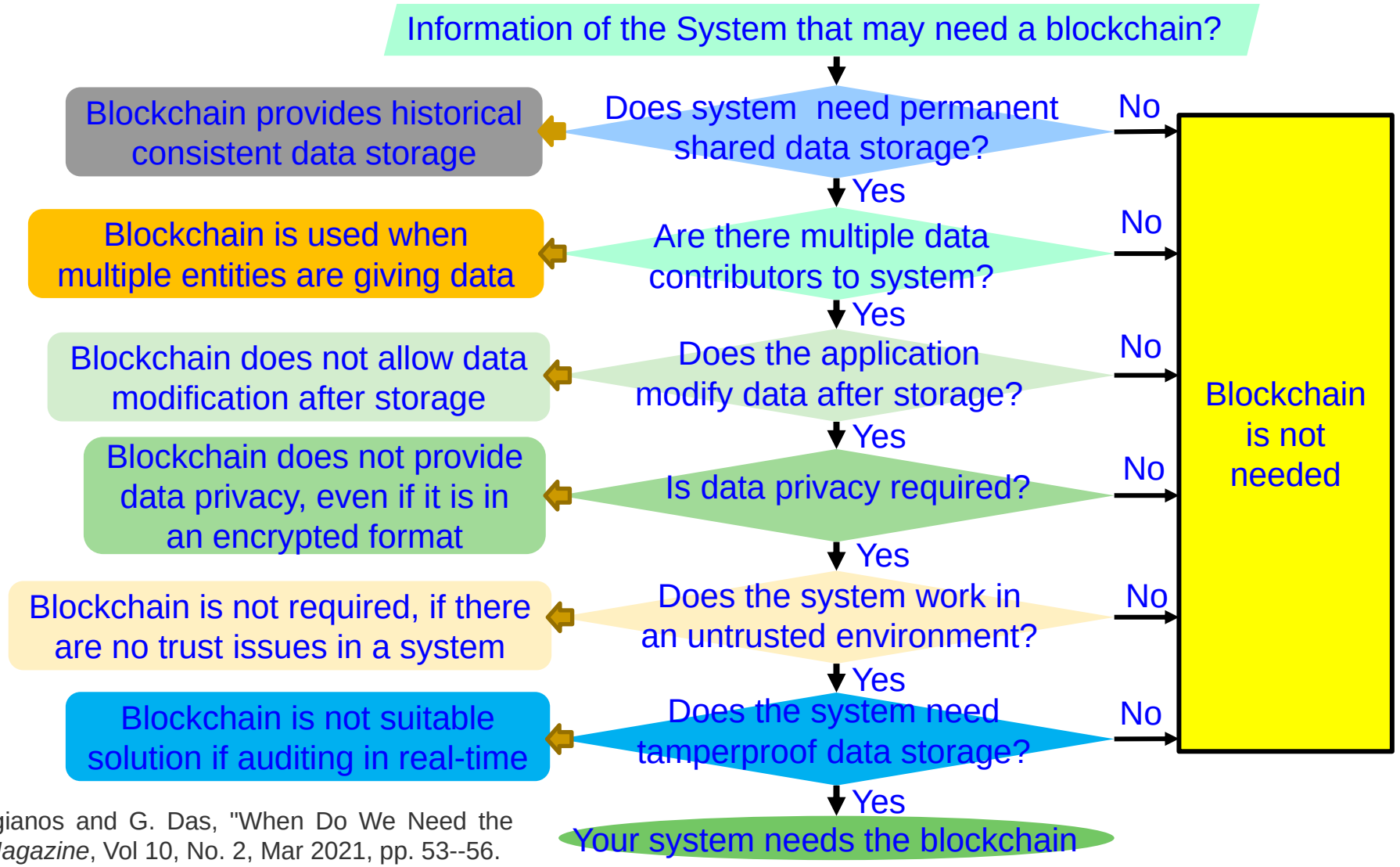


Technical Definition: A blockchain is a linked list that is built with hash pointers instead of regular pointers.
Socio-Political–Economic Definition: A blockchain is an open, borderless, decentralized, public, trustless, permissionless, immutable record of transactions.
Financial – Accounting Definition: A blockchain is a public, distributed ledger of peer-to-peer transactions.

Source: D. Puthal, N. Malik, S. P. Mohanty, E. Kougianos, and C. Yang, "The Blockchain as a Decentralized Security Framework", *IEEE Consumer Electronics Magazine (CEM)*, Volume 7, Issue 2, March 2018, pp. 18--21.

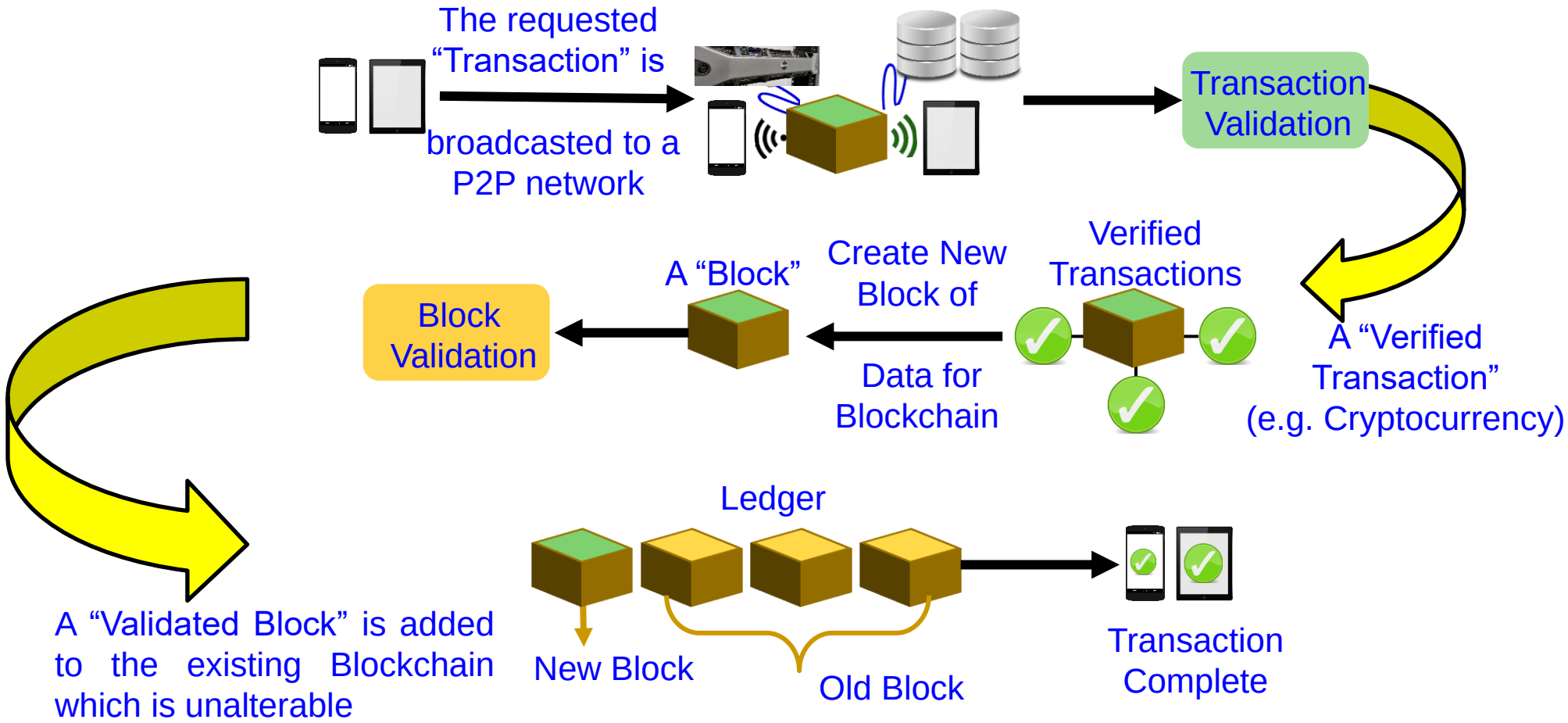
When do You Need the Blockchain?





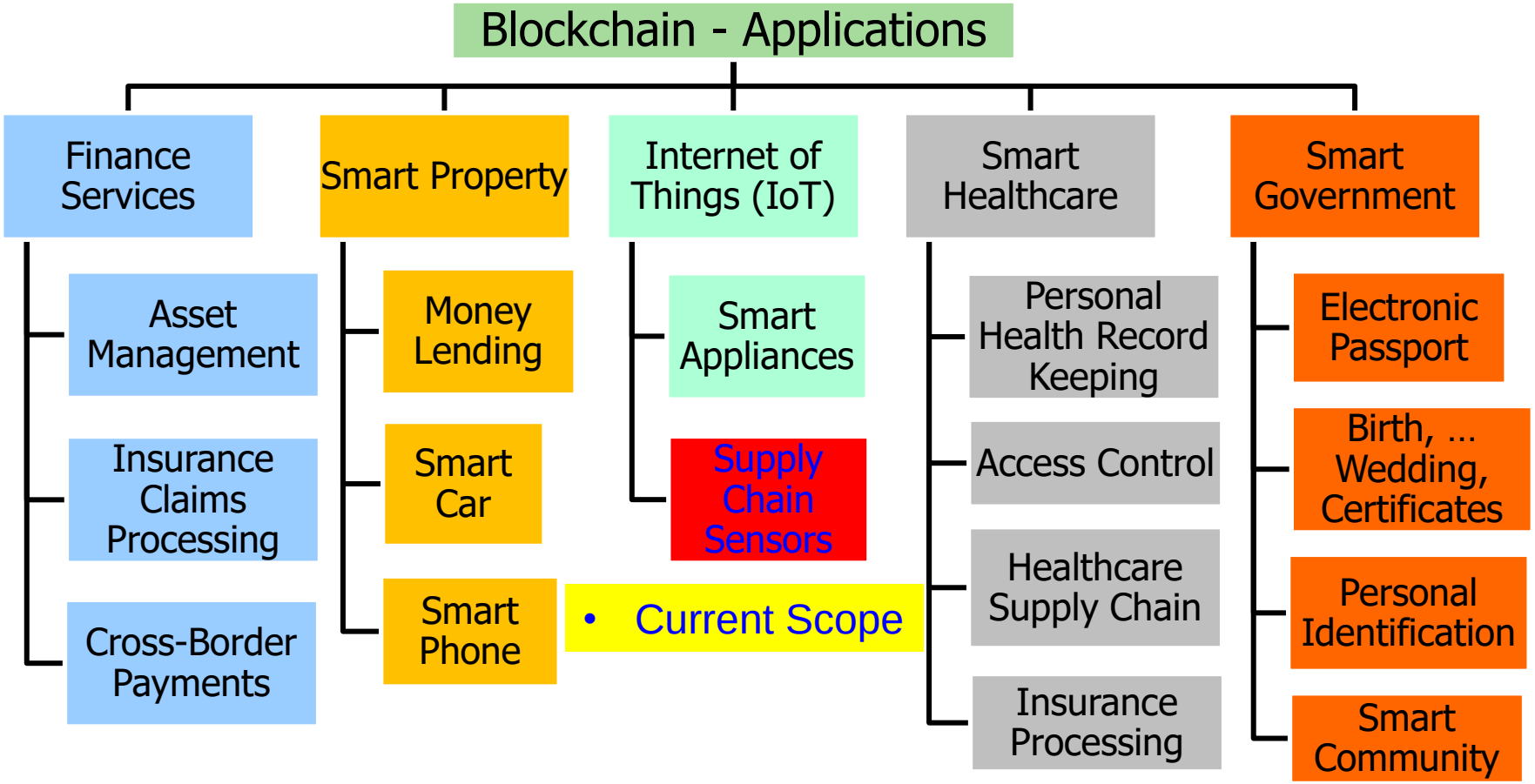
Source: D. Puthal, S. P. Mohanty, E. Kougianos and G. Das, "When Do We Need the Blockchain?," *IEEE Consumer Electronics Magazine*, Vol 10, No. 2, Mar 2021, pp. 53--56.

Blockchain Transaction Steps



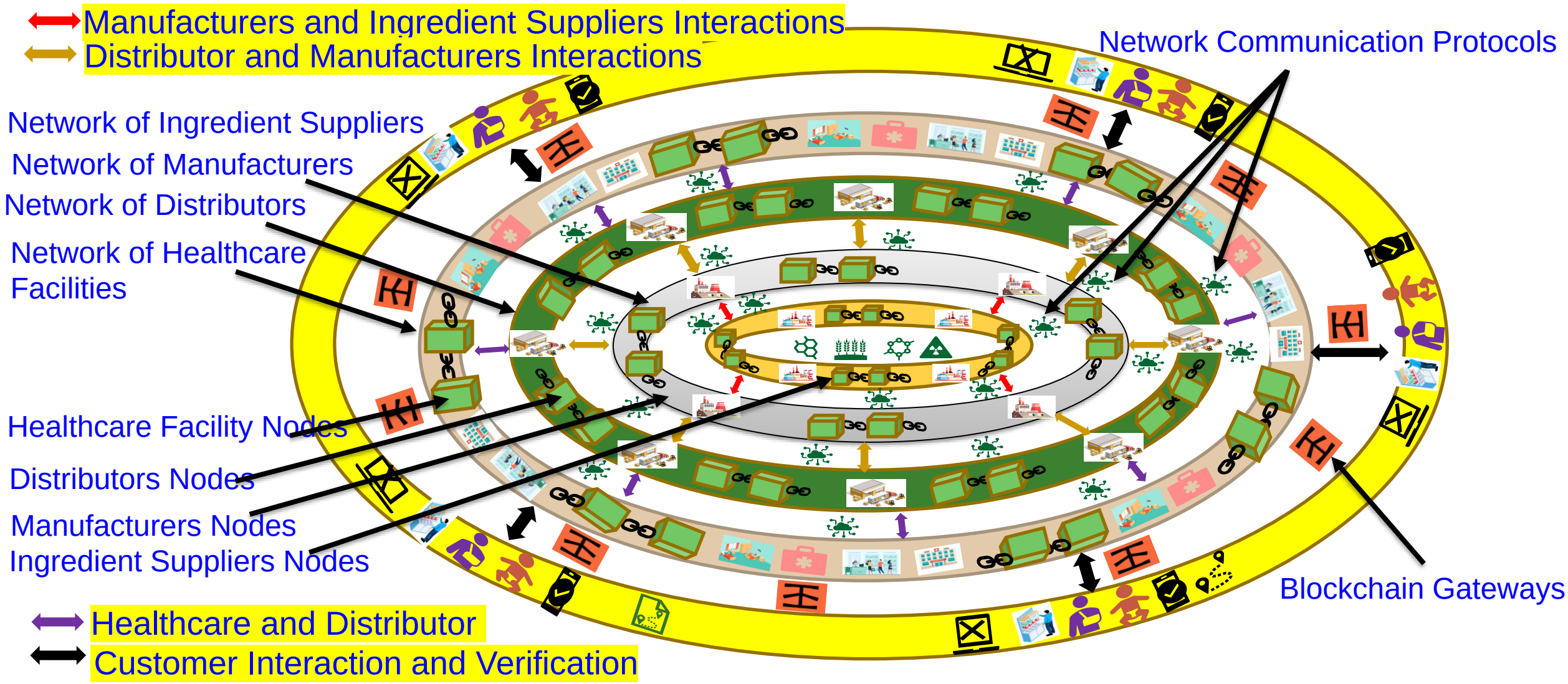
Source: Deepak Puthal, Nisha Malik, Saraju P. Mohanty, Elias Kougianos, and Gautam Das, "Everything you Wanted to Know about the Blockchain", *IEEE Consumer Electronics Magazine*, Vol. 8, No. 4, pp. 6--14, 2018.

Blockchain Applications



Source: D. Puthal, N. Malik, S. P. Mohanty, E. Kougianos, and G. Das, "Everything you Wanted to Know about the Blockchain", *IEEE Consumer Electronics Magazine (CEM)*, Volume 7, Issue 4, July 2018, pp. 06--14.

Blockchain Leveraged Healthcare CPS

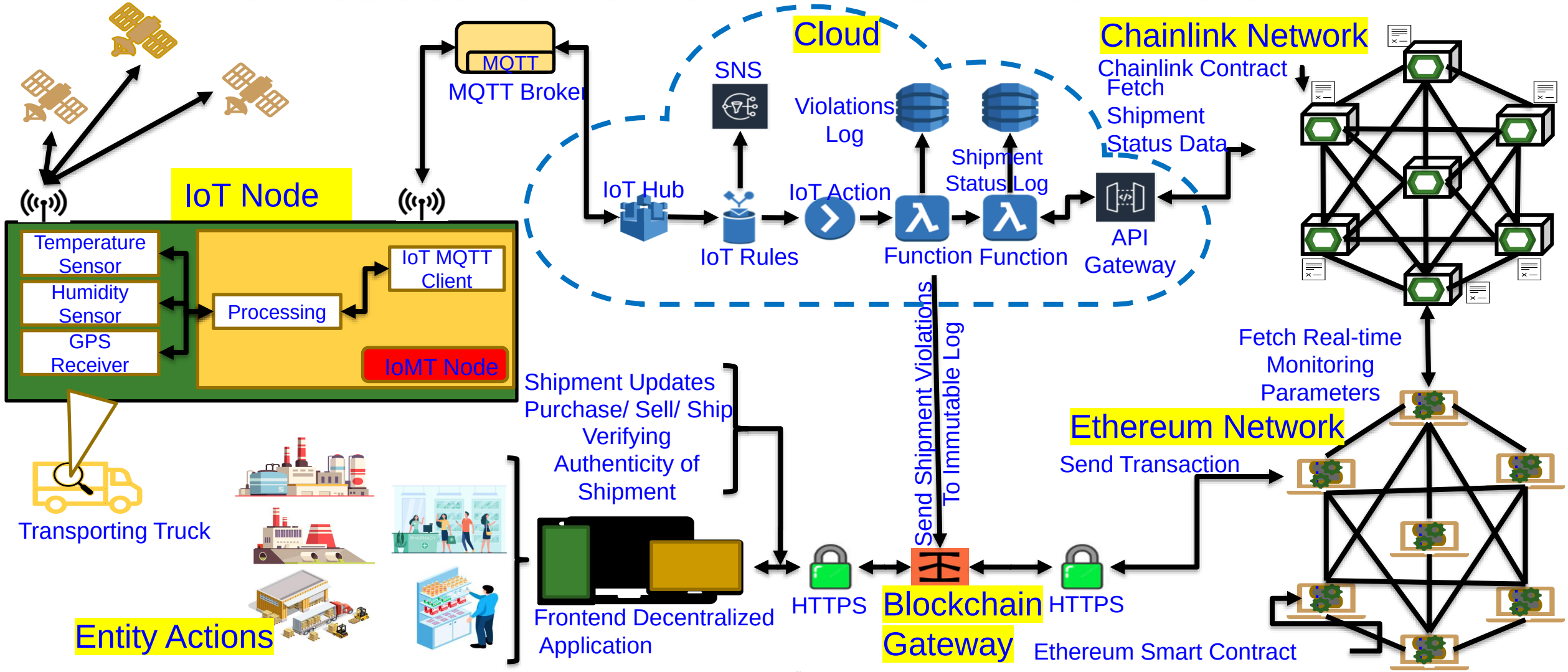


Source: Bapatla, A.K., et al.: PharmaChain: a blockchain to ensure counterfeit-free pharmaceutical supply chain. IET Netw. 1– 24 (2022). https://doi.org/10.1049/ntw2.12041

Our First Work to Transparent Pharmaceutical Supply Chains

PharmaChain: A Blockchain to Ensure Counterfeit-Free Pharmaceutical Supply Chain

Architectural Overview of PharmaChain

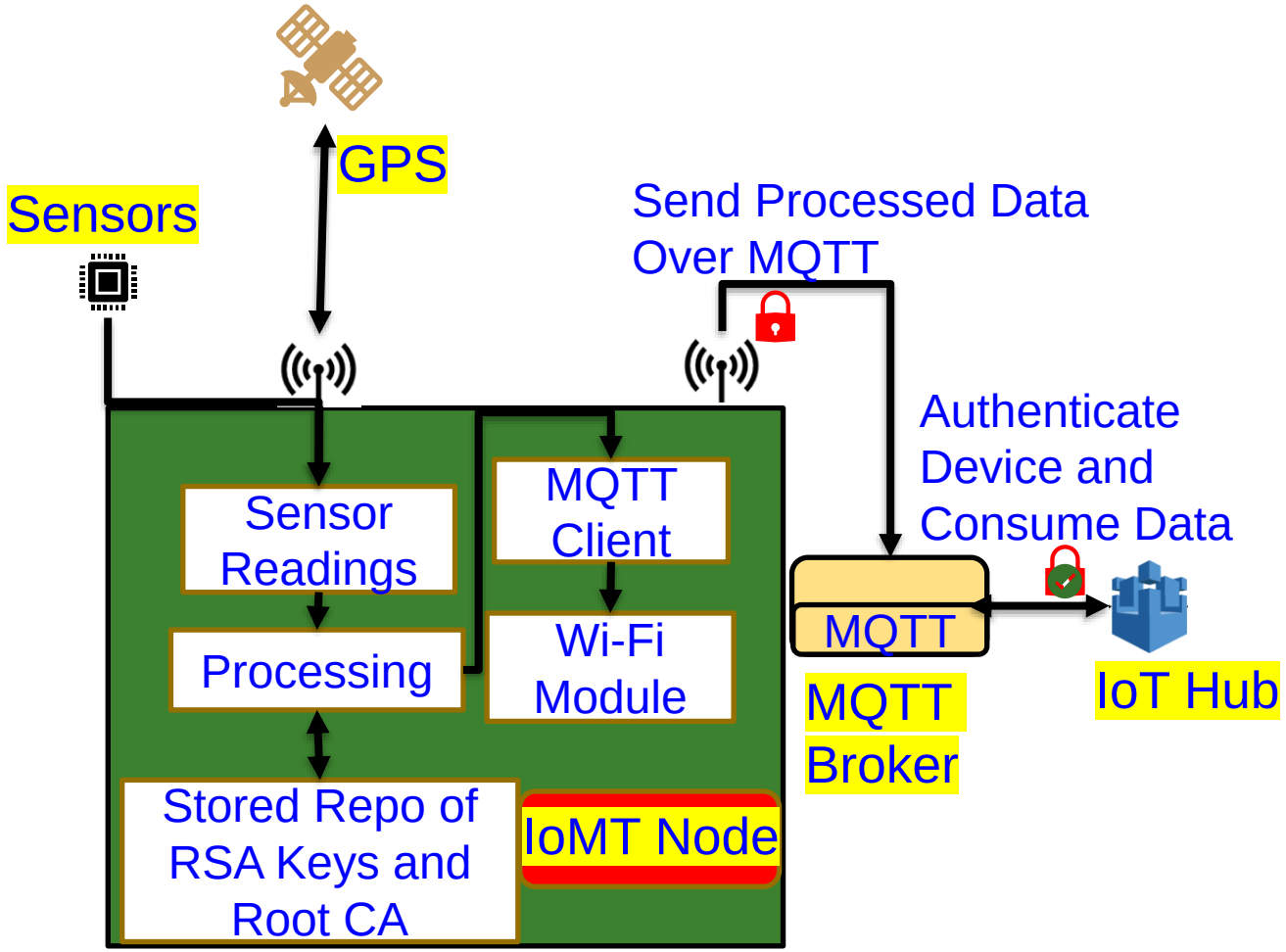


Source: A. K. Bapatla, **S. P. Mohanty**, E. Kougianos, D. Puthal, and A. Bapatla, "PharmaChain: A Blockchain to Ensure Counterfeit-Free Pharmaceutical Supply Chain", *IET Networks*, Vol. XX, No. YY, ZZ 2022, pp. Accepted on 24 June 2022, DOI: https://doi.org/10.1049/ntw2.12041. (Dataset for Research: GitHub)

Novel Contributions

- Expedite the order processing and prompt decision making
- Information fragmentation issue is addressed
- Detecting counterfeits easily in the supply chain
- Increasing accountability of participating entities
- Drug recall process made easier
- Real-time decision support tool is provided for pharmaceutical supply chains

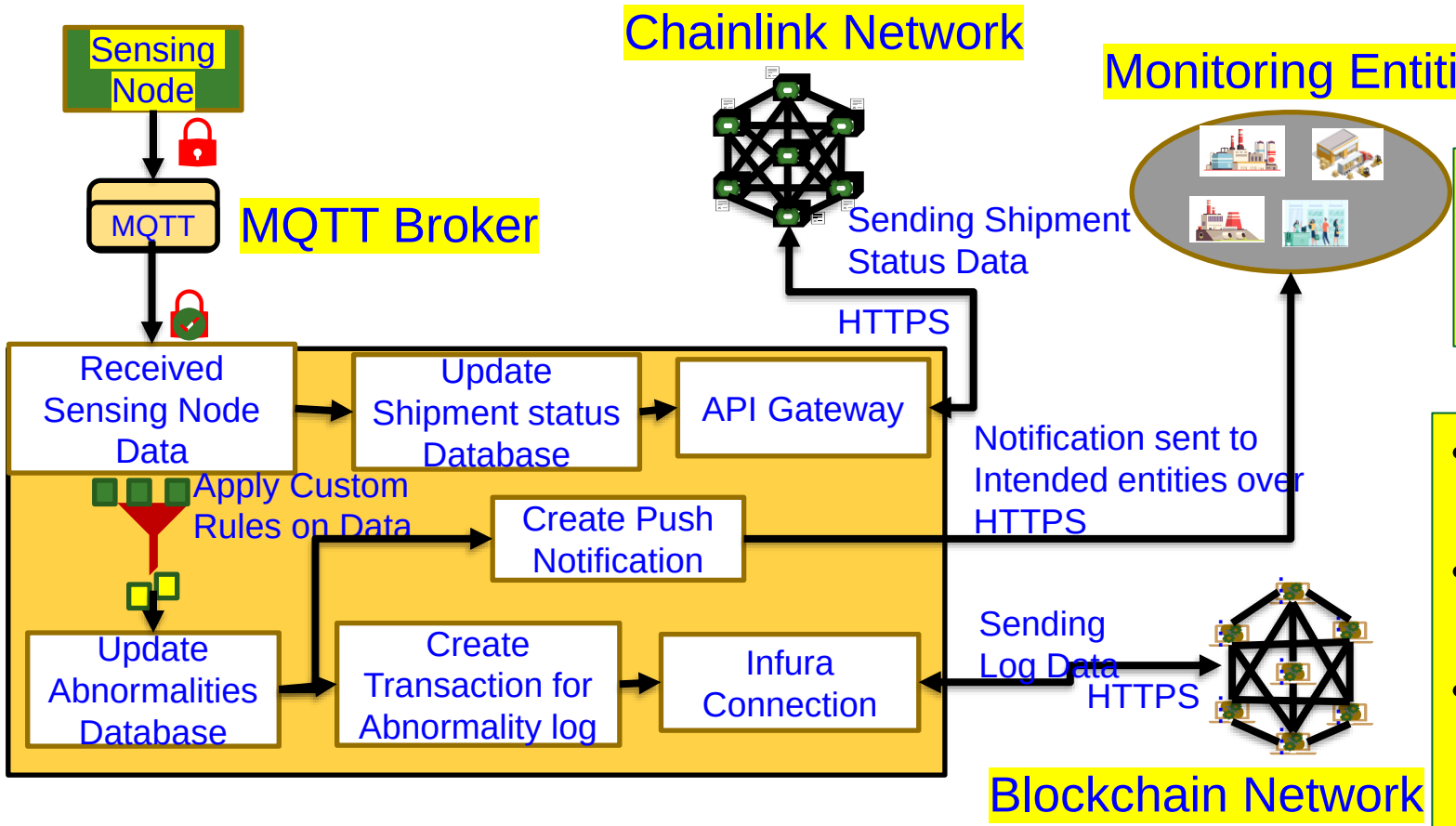
PharmaChain Sensing Node



- Designed to monitor important parameters for pharmaceutical shipment which include temperature, humidity along with GPS coordinates of the shipment
- Monitoring data from sensing nodes will be processed and formatted into a JSON file before being sent to the cloud component
- Lightweight Message Queuing Telemetry Transport (MQTT) protocol and topics are used

Source: Bapatla, A.K., et al.: PharmaChain: a blockchain to ensure counterfeit-free pharmaceutical supply chain. IET Netw. 1– 24 (2022). https://doi.org/10.1049/ntw2.12041

PharmaChain Cloud Component

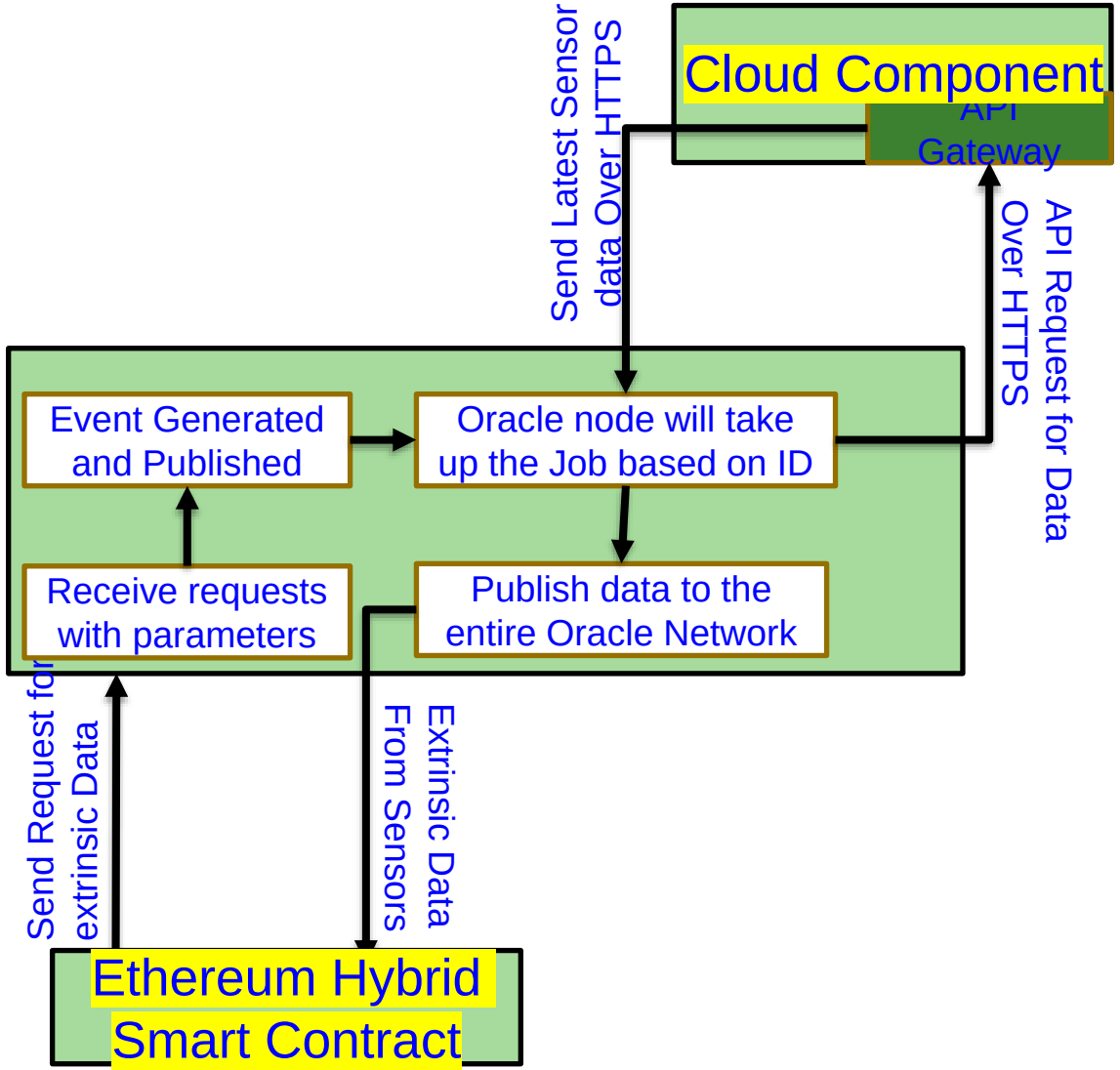


- Smart contracts cannot interact with API or external environmental data

- Cloud component used for designing data provider for Oracle.
- Data feeds to the smart contracts are done by Oracles.
- It is simply decentralized verifiable data to integrate smart contracts with external data feeds.

Source: Bapatla, A.K., et al.: PharmaChain: a blockchain to ensure counterfeit-free pharmaceutical supply chain. IET Netw. 1– 24 (2022). https://doi.org/10.1049/ntw2.12041

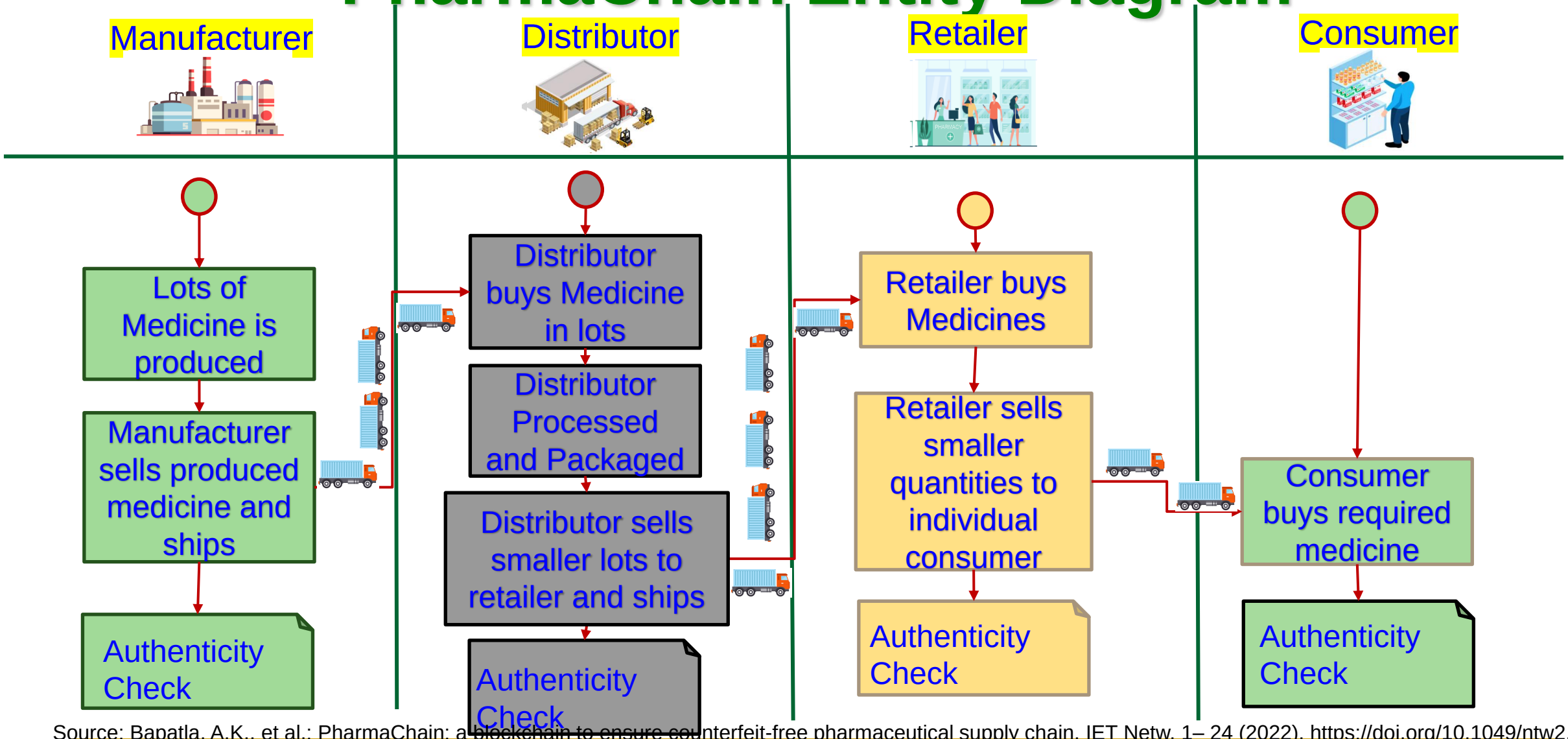
PharmaChain Oracle Component



- Multiple jobs are executed to fetch the data instead of a single job
- Results from multiple jobs are aggregated
- Aggregated data is published to hybrid smart contract

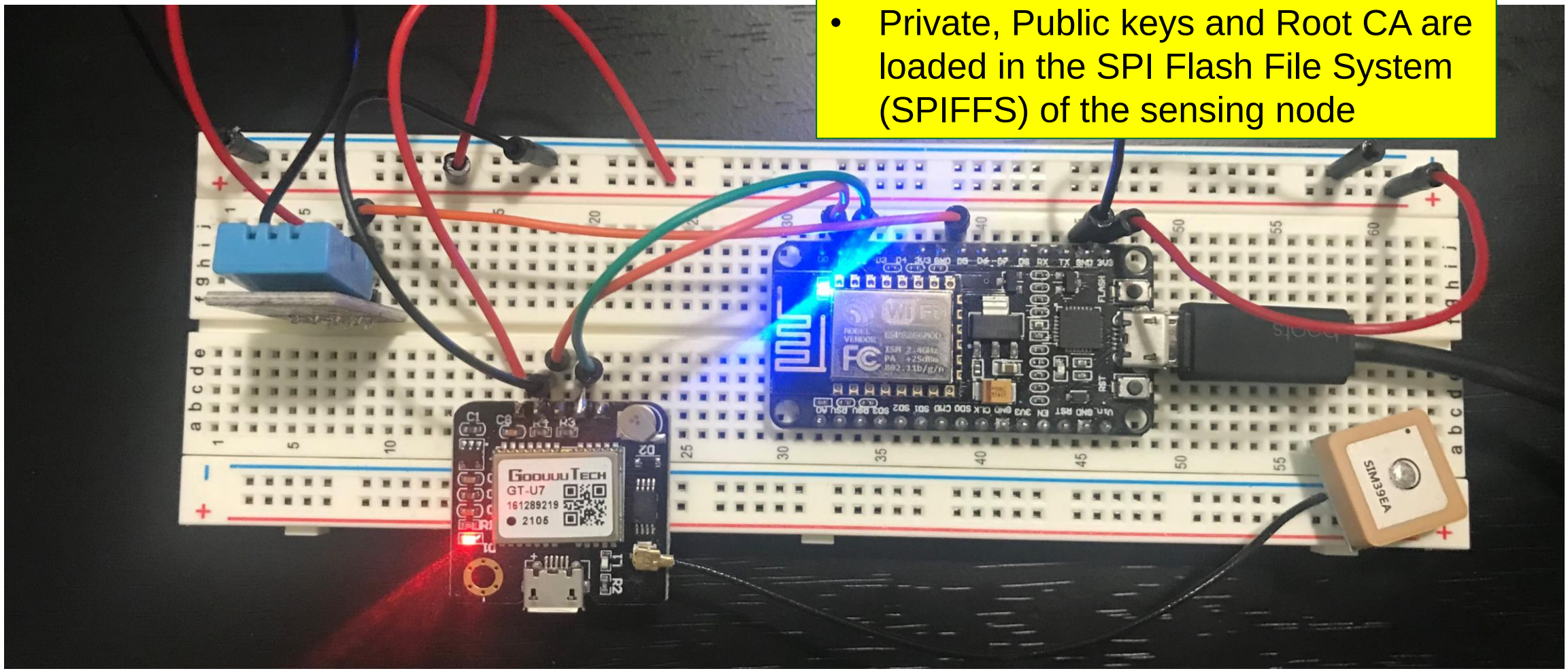
Source: Bapatla, A.K., et al.: PharmaChain: a blockchain to ensure counterfeit-free pharmaceutical supply chain. IET Netw. 1– 24 (2022). https://doi.org/10.1049/ntw2.12041

PharmaChain Entity Diagram



Source: Bapatla, A.K., et al.: PharmaChain: a blockchain to ensure counterfeit-free pharmaceutical supply chain. IET Netw. 1– 24 (2022). https://doi.org/10.1049/ntw2.12041

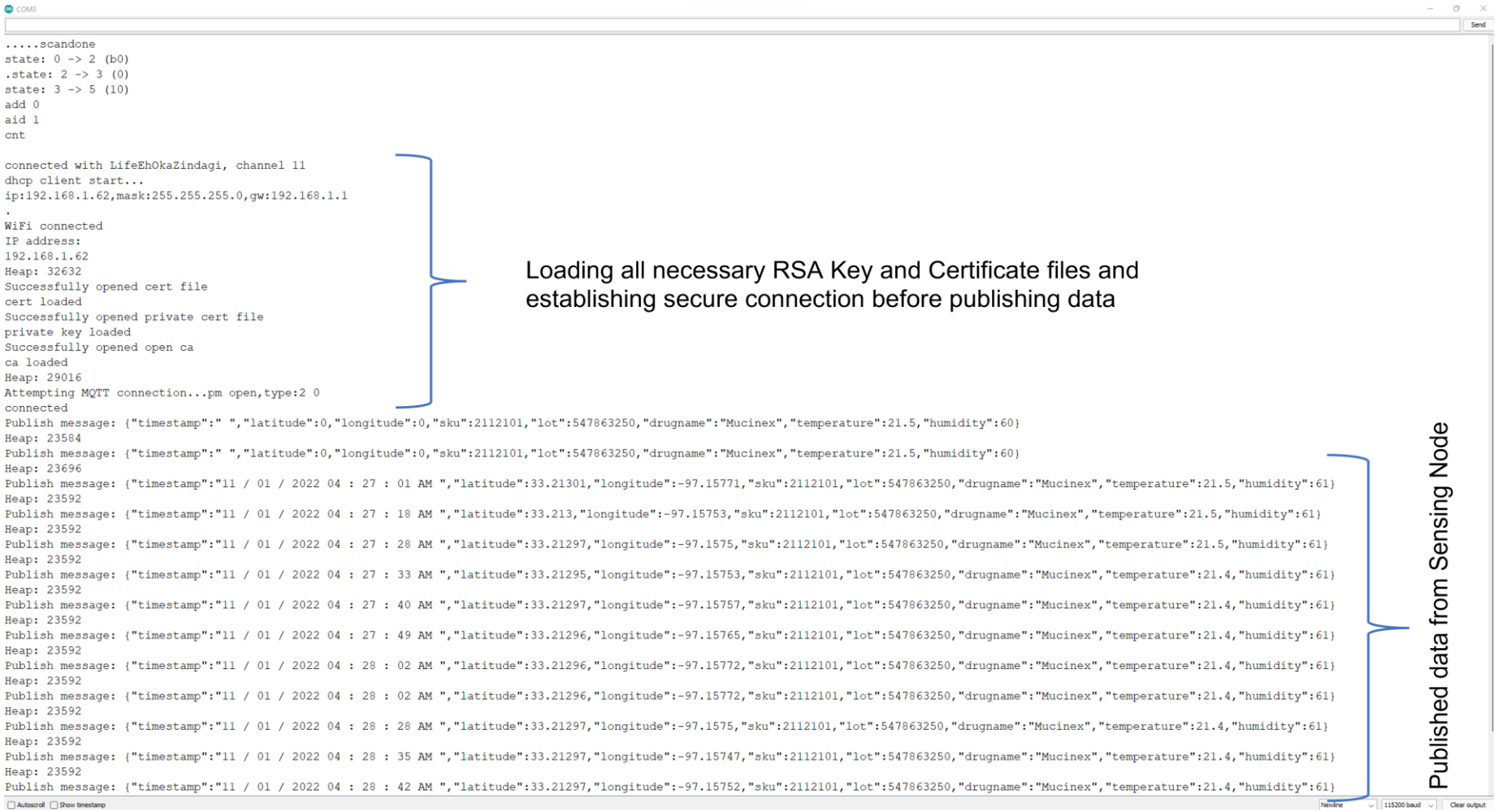
Designed Sensing Node



- Private, Public keys and Root CA are loaded in the SPI Flash File System (SPIFFS) of the sensing node

Source: Bapatla, A.K., et al.: PharmaChain: a blockchain to ensure counterfeit-free pharmaceutical supply chain. IET Netw. 1– 24 (2022). https://doi.org/10.1049/ntw2.12041

Sensing Node Data



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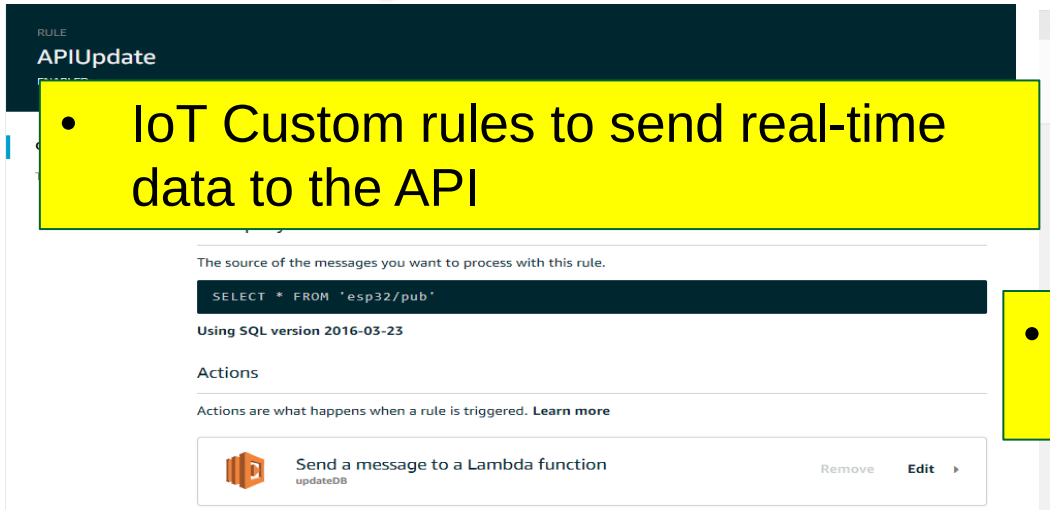
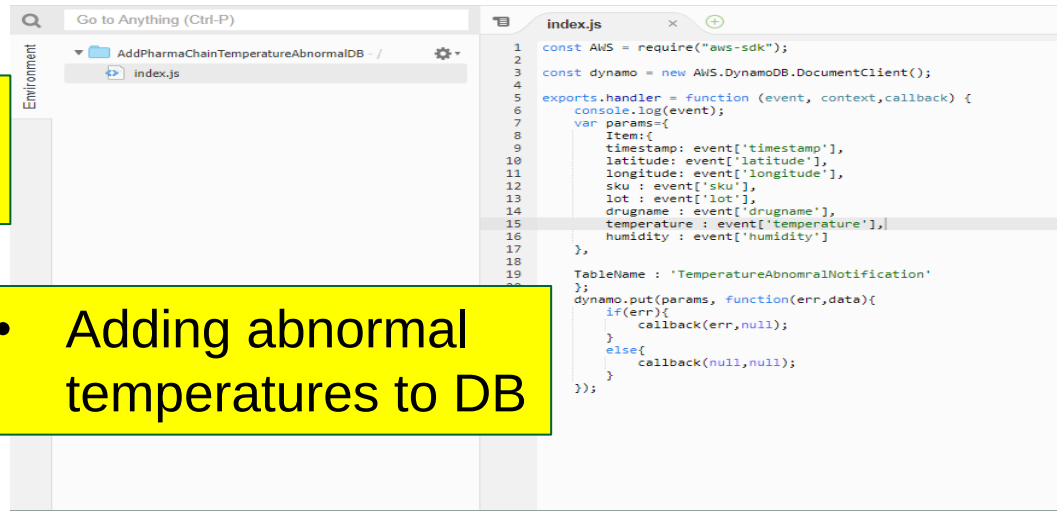
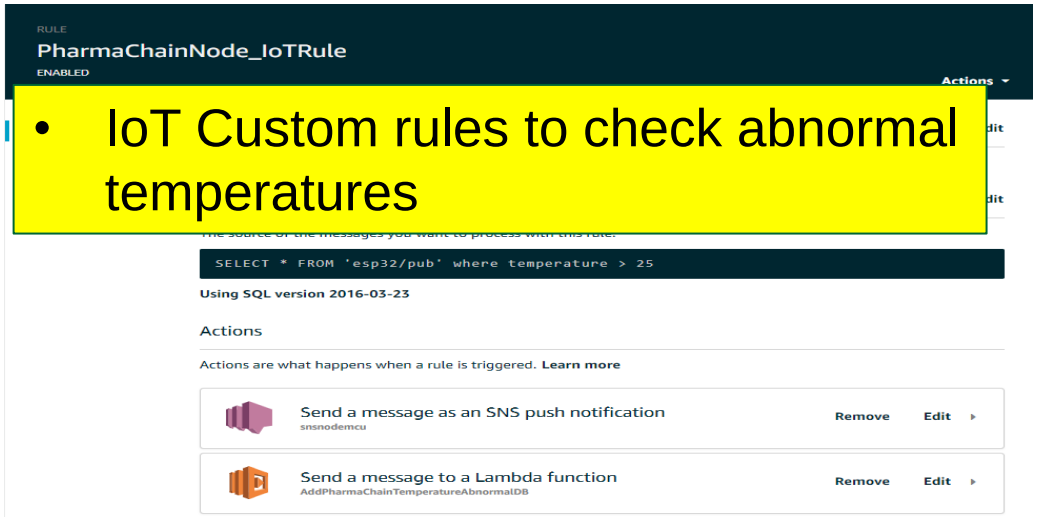
Implemented Cloud Component



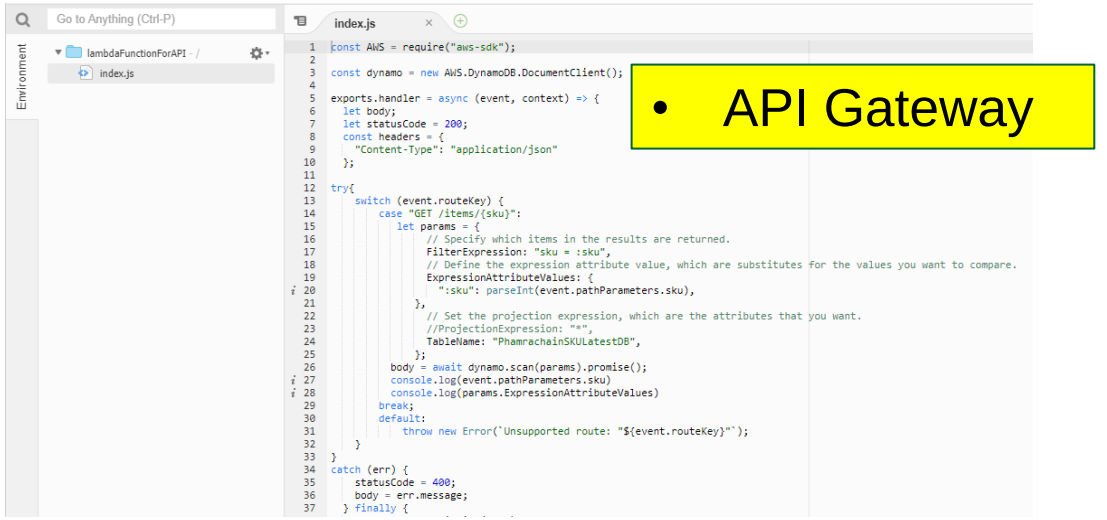
- IoT Custom rules to send real-time data to the API



- Adding abnormal temperatures to DB



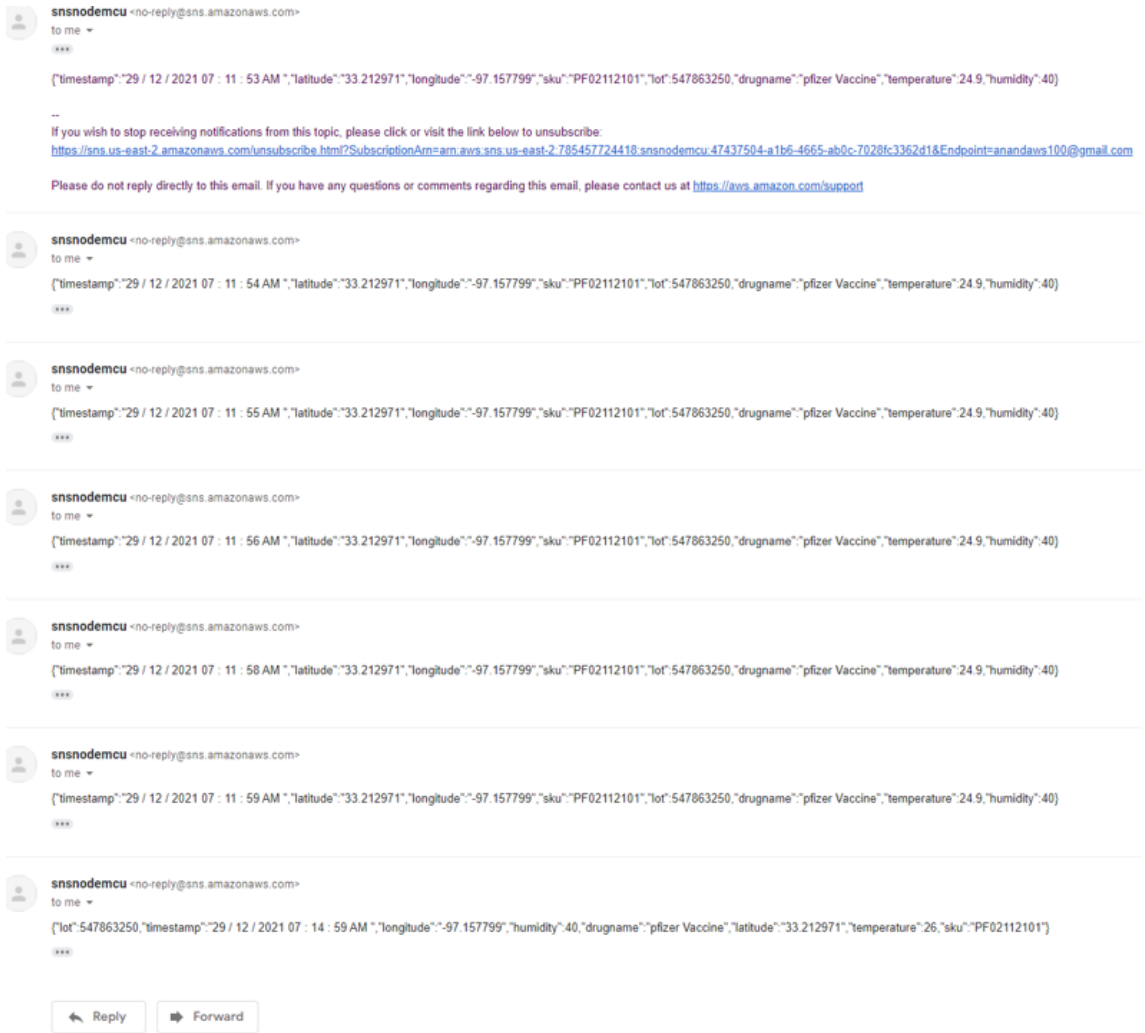
- IoT Custom rules to check abnormal temperatures



- API Gateway

Source: Bapatla, A.K., et al.: PharmaChain: a blockchain to ensure counterfeit-free pharmaceutical supply chain. IET Netw. 1– 24 (2022). https://doi.org/10.1049/ntw2.12041

Alerts Generated



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to me

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https://sns.us-east-2.amazonaws.com/unsubscribe.html?SubscriptionArn=arn:aws:sns:us-east-2:785457724418:snsnodemcu:47437504-a1b6-4665-ab0c-7028fc3362d1&Endpoint=anandaws100@gmail.com

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to me

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Reply Forward

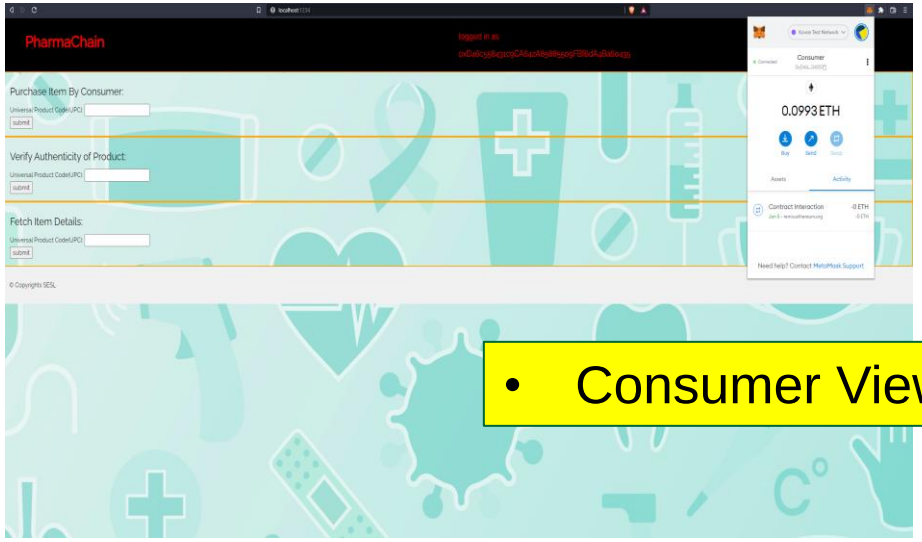
Source: Bapatla, A.K., et al.: PharmaChain: a blockchain to ensure counterfeit-free pharmaceutical supply chain. IET Netw. 1– 24 (2022). https://doi.org/10.1049/ntw2.12041

Web DApp Interface

- Manufacturer View

- Distributor View

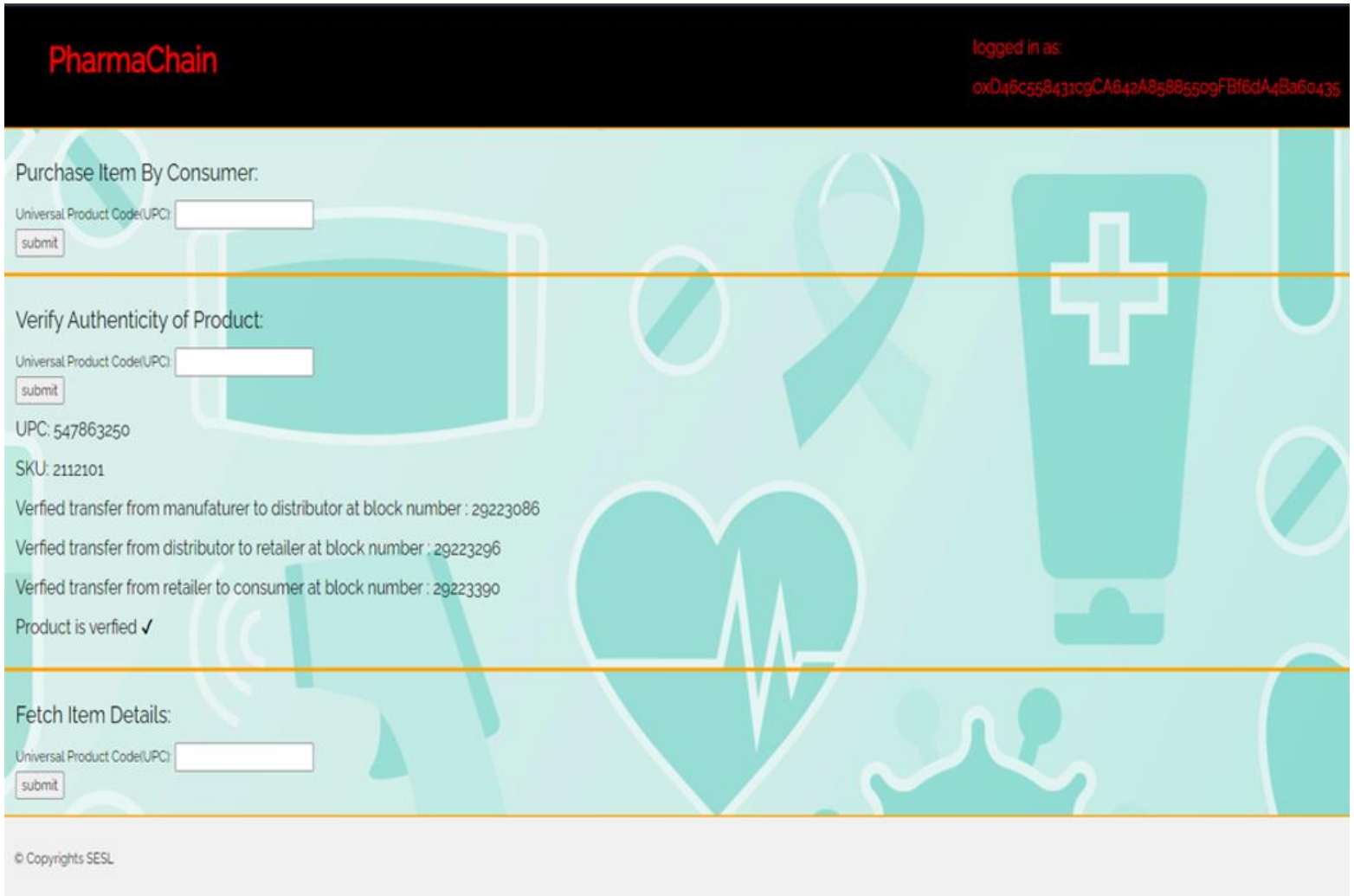
- Retailer View



- Consumer View

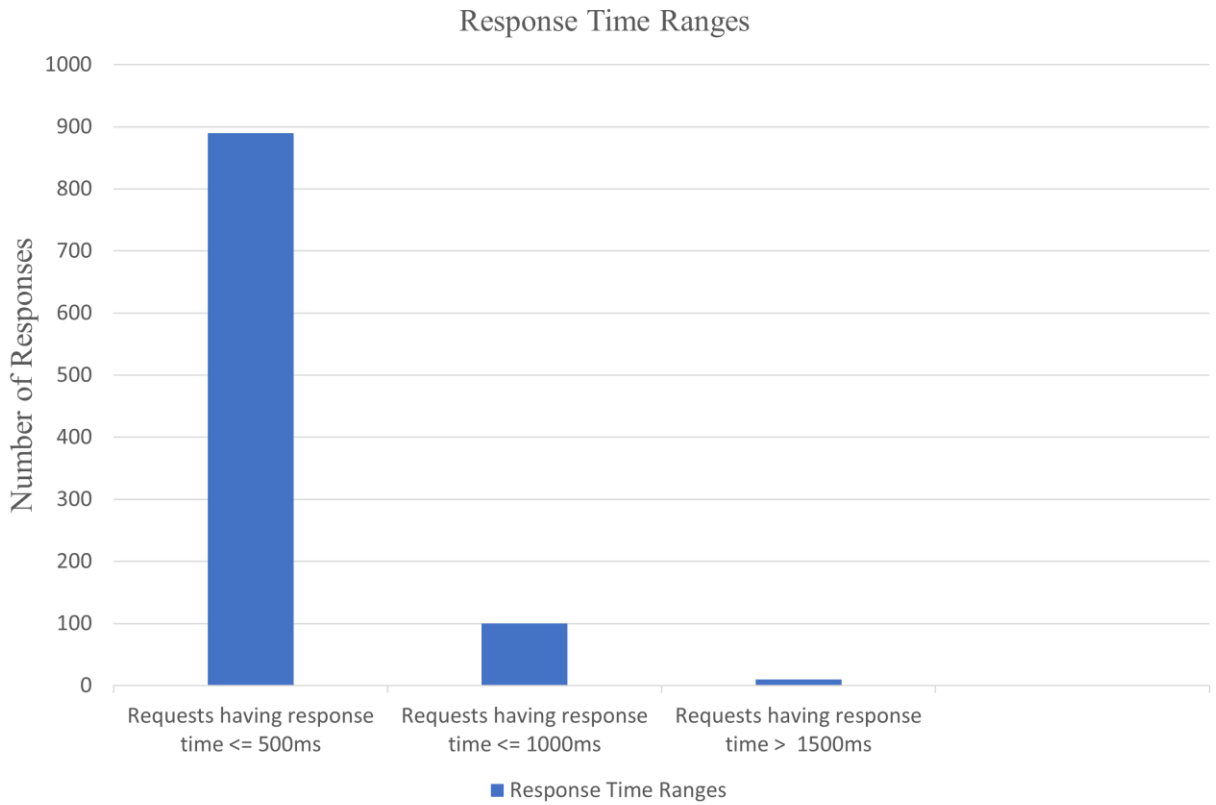
Source: Bapatla, A.K., et al.: PharmaChain: a blockchain to ensure counterfeit-free pharmaceutical supply chain. IET Netw. 1– 24 (2022). https://doi.org/10.1049/ntw2.12041

Consumer Verifying Authenticity



Source: Bapatla, A.K., et al.: PharmaChain: a blockchain to ensure counterfeit-free pharmaceutical supply chain. IET Netw. 1– 24 (2022). https://doi.org/10.1049/ntw2.12041

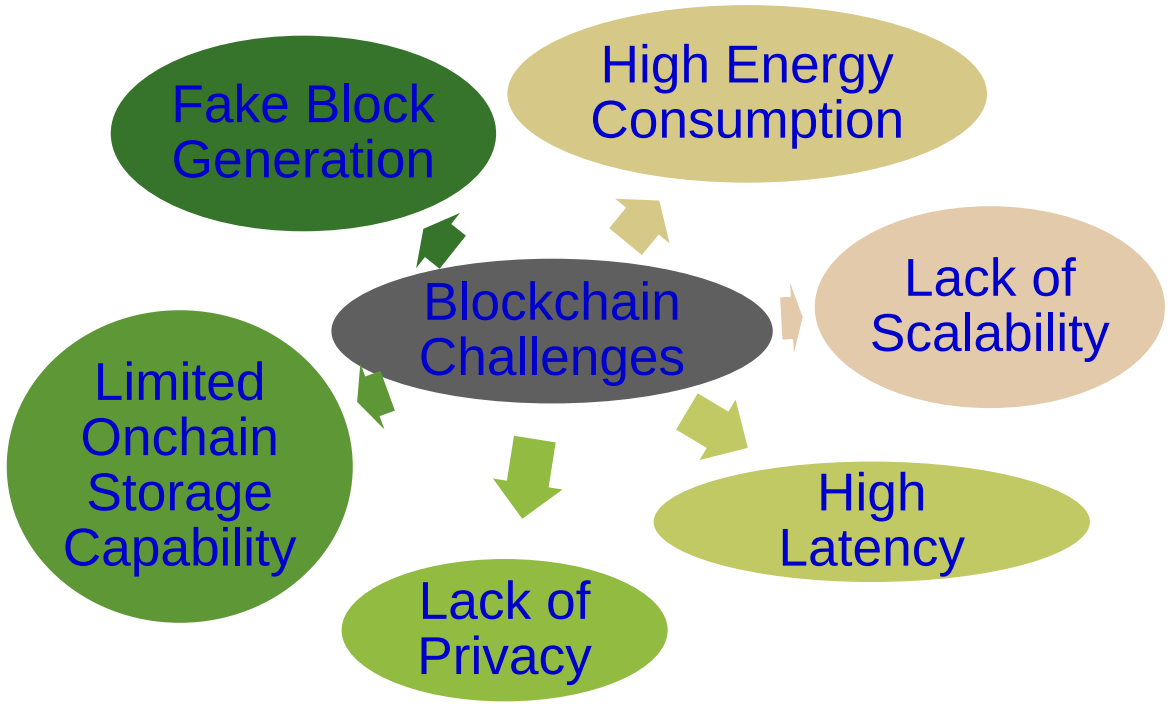
Performance and Cost Analysis

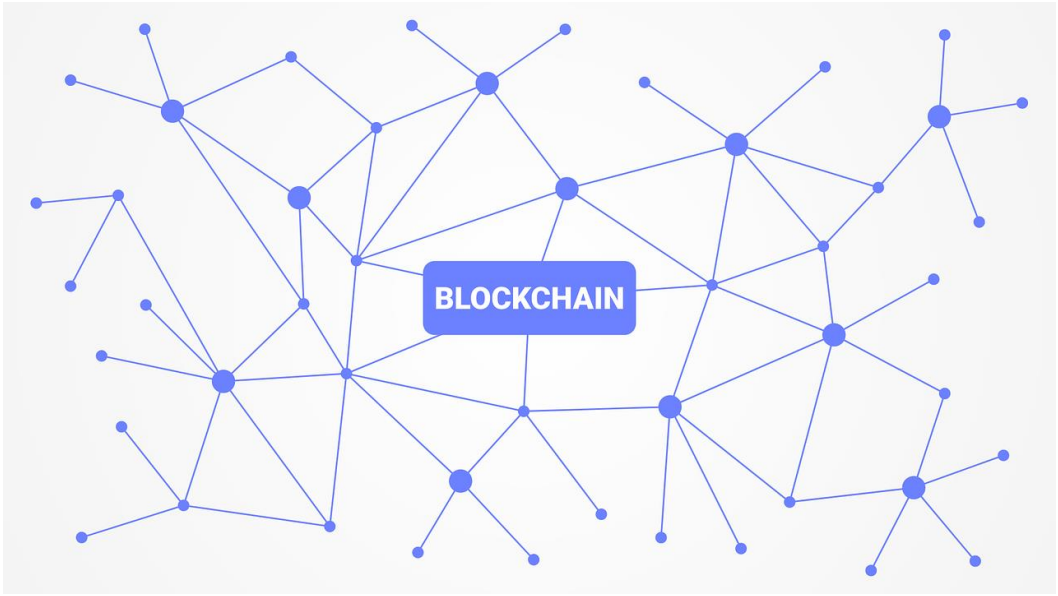


Parameters	Value
Number of Oracle Requests sent	1000
Load Duration	2 Seconds
Failed Requests	0
Percentage of Error	0%
Average Response Time (ms)	285.196 ms
Maximum Response Time (ms)	78ms
Throughput (requests/sec)	16.66

Source: Bapatla, A.K., et al.: PharmaChain: a blockchain to ensure counterfeit-free pharmaceutical supply chain. IET Netw. 1– 24 (2022). https://doi.org/10.1049/ntw2.12041

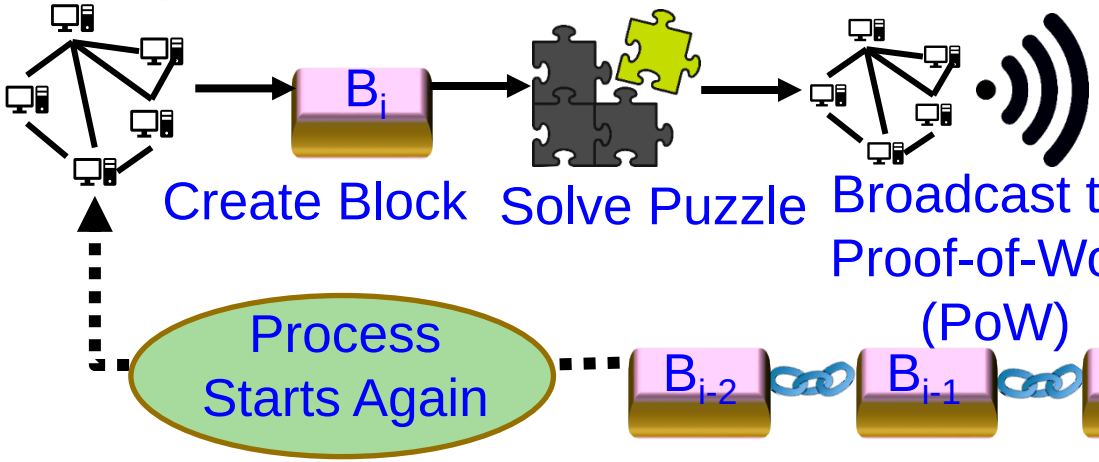
Blockchain has Many Challenges





Source: D. Puthal, N. Malik, S. P. Mohanty, E. Kougianos, and G. Das, “Everything you Wanted to Know about the Blockchain”, *IEEE Consumer Electronics Magazine (CEM)*, Volume 7, Issue 4, July 2018, pp. 06--14.

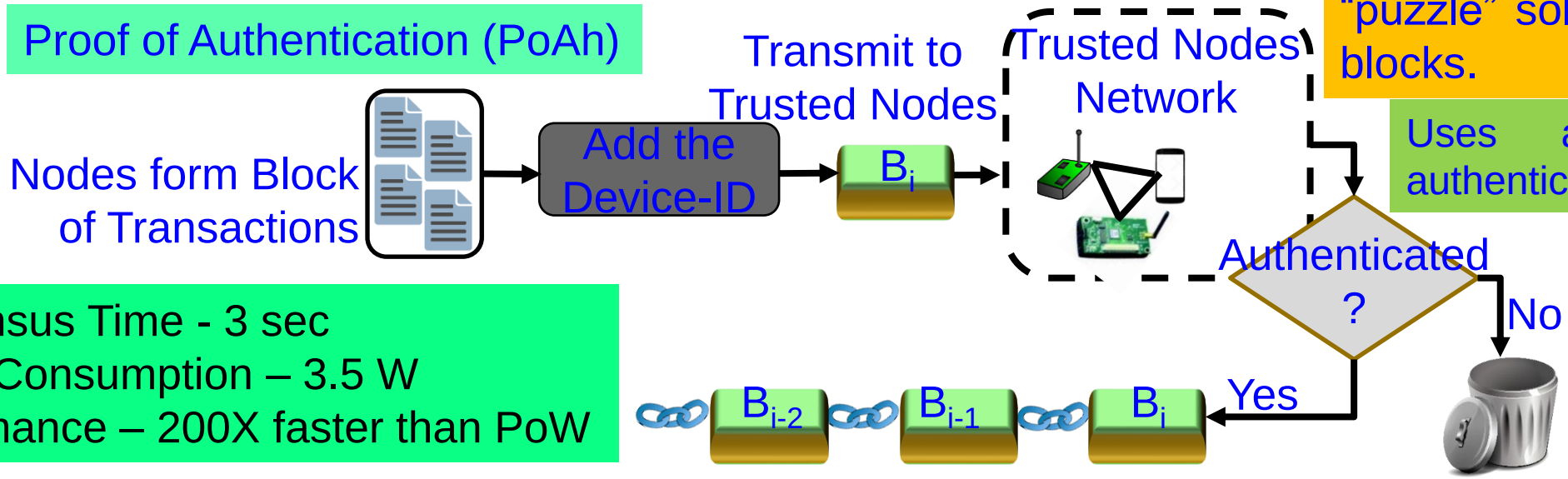
Our EasyChain: Proof-of-Authentication (PoAh)



Proof-of-Work (PoW)

Eliminates cryptographic "puzzle" solving to validate blocks.

Proof of Authentication (PoAh)

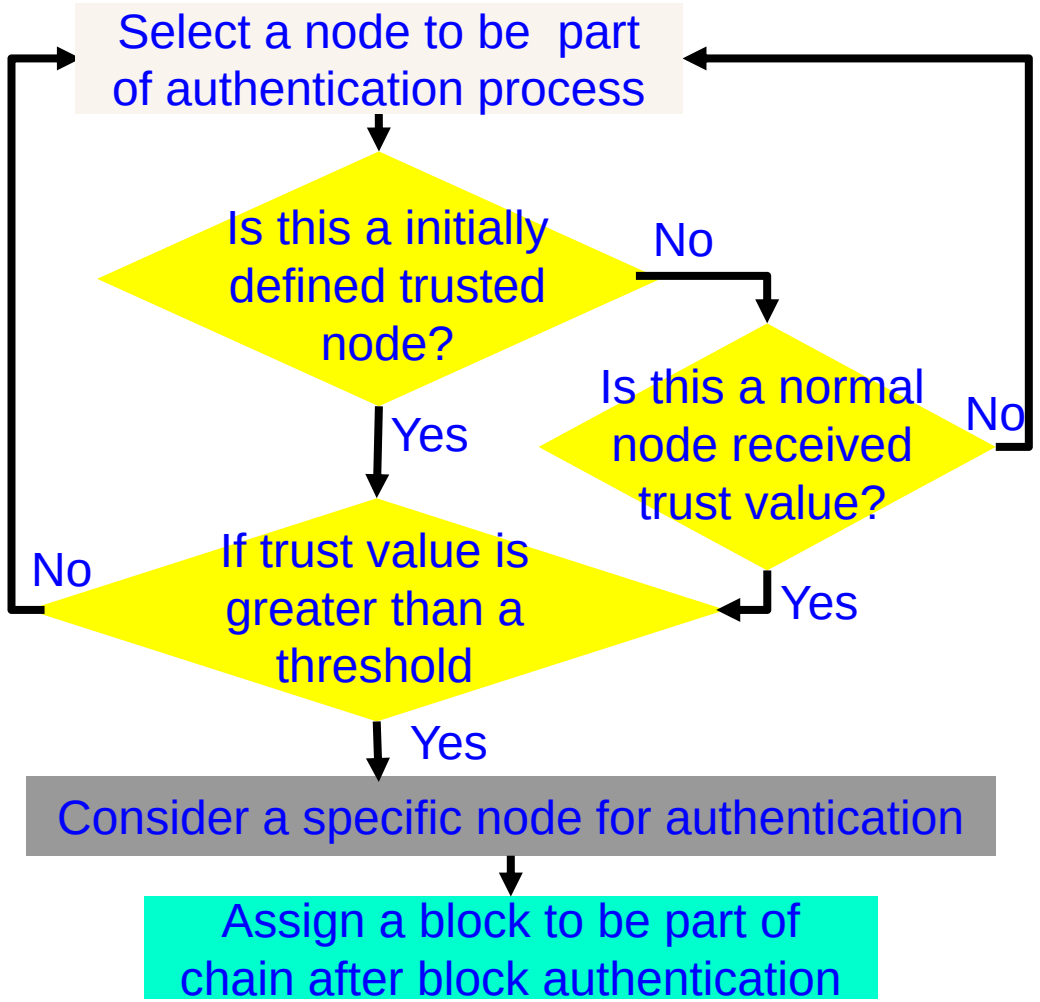


Uses a cryptographic authentication mechanism.

Consensus Time - 3 sec
Power Consumption – 3.5 W
Performance – 200X faster than PoW

Source: D. Puthal and S. P. Mohanty, "Proof of Authentication: IoT-Friendly Blockchains", *IEEE Potentials Magazine*, Vol. 38, No. 1, January 2019, pp. 26--29.

Our EasyChain: PoAh Authentication Process



Algorithm 1: PoAh Block Authentication

Provided:
All nodes in the network follow SHA-256 Hash
Individual node has Private (PrK) and Public key (PuK)
Steps:
(1) Nodes combine transactions to form blocks
  (Trx^{+}) → blocks
(2) Blocks sign with own private key
  S_{PrK} (block) → broadcast
(3) Trusted node verifies signature with source public key
  V_{PuK}(block) → MAC Checking
(4) If (Authenticated)
  Block||PoAh(ID) → broadcast
  H(block) → Add blocks into chain
(5) Else
  Drop blocks
(6) GOTO (Step-1) for next block

Steps to find a Trusted Node which will Authenticate a Block.

Source: D. Puthal and S. P. Mohanty, "Proof of Authentication: IoT-Friendly Blockchains", *IEEE Potentials Magazine*, Vol. 38, No. 1, January 2019, pp. 26--29.

Addressing Blockchain Scalability Issues and Control During Transport

PharmaChain 2.0: A Blockchain Framework for Secure Remote Monitoring of Drug Environmental Parameters in Pharmaceutical Cold Supply Chain

Issues in Traditional PSC

08/22/2022

BEAUMONT, Texas – A Florida-based pharmaceutical president has pleaded guilty to federal drug trafficking violations in the Eastern District of Texas, announced U.S. Attorney Brit Featherston toda

11/12/2021

A federal grand jury in Beaumont has returned a three-count indictment charging nine individuals in drug trafficking conspiracy in the Eastern District of Texas, announced Acting U.S. Attorney Nicholas J. Ganjei today

08/24/2021

ALEX NDRIA, Va. – An Inverness, Florida, man was sentenced today to three years in prison for selling hundreds of thousands of counterfeit prescription drug pills through the Internet.

News Source: Affairs, O. of R. (n.d.). *Press releases*. U.S. Food and Drug Administration. Retrieved November 15, 2022, from https://www.fda.gov/inspections-compliance-enforcement-and-criminal-investigations/criminal-investigations/press-releases

Motivation

- Temperature-controlled drug's life cycle includes:
  - Monitoring and controlling the temperature during the storage of medicines in warehouses.
  - Maintaining the temperature ranges during the transportation of drugs.
  - Packaging should be taken care of following all recommended procedures.
  - Pharmacies and care sites should be properly equipped to maintain the medication temperature until dispensed.

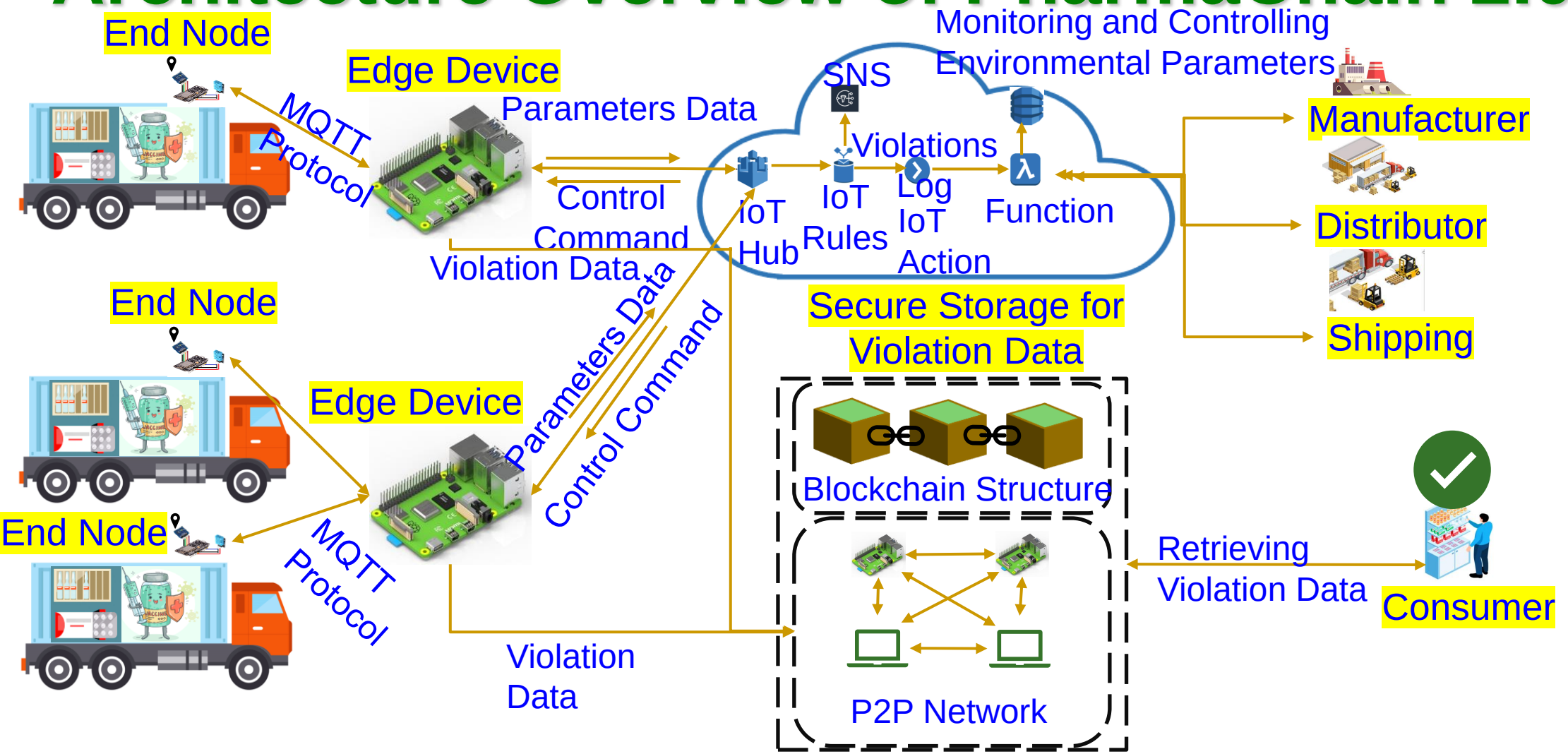
Novel Contributions

- Near real-time data will be propagated in the P2P network. Hence, prompt action can be taken to prevent decreases in drug efficacy.
- Consensus in the proposed P2P network will make the system more robust to different security threats.
- PharmaChain 2.0 makes use of IoT systems to provide continuous monitoring and control throughout the drug life cycle in the supply chain.
- Data security is provided by using the immutable characteristic of blockchain.
- PharmaChain 2.0 provides a cost-efficient infrastructure that can be adapted on a large scale as cold supply chains are huge.

PharmaChain Versus PharmaChain 2.0

PharmaChain	PharmaChain 2.0
Ethereum Blockchain Used for Tracking and Tracing in Pharmaceutical Supply Chain	PoAh Consensus Based Blockchain, used for both Tracking & Tracing along with Monitoring and Controlling Temperature Excursions
Proof-of-Authority (PoA) with less throughput compared to PoAh	Proof-of-Authentication (PoAh) with higher throughput
Private Blockchain with only nodes participating from Entities	Private Blockchain with only nodes participating from Entities
Not IoT friendly Consensus	IoT Friendly Consensus with less power and computations
The average transaction processing time is 5.6 sec.	The average transaction time has been improved significantly to 322.28ms

Architecture Overview of PharmaChain 2.0



Source: A. K. Bapatla, **S. P. Mohanty**, E. Kougianos, and D. Puthal, "PharmaChain 2.0: A Blockchain Framework for Secure Remote Monitoring of Drug Environmental Parameters in Pharmaceutical Cold Supply Chain", in *Proceedings of the IEEE International Symposium on Smart Electronic Systems (iSES)*, 2022, pp. Accepted.

Proposed Algorithms – Log Generation

Algorithm 1 Proposed Violation Data Log Generation Algorithm For PharmaChain 2.0

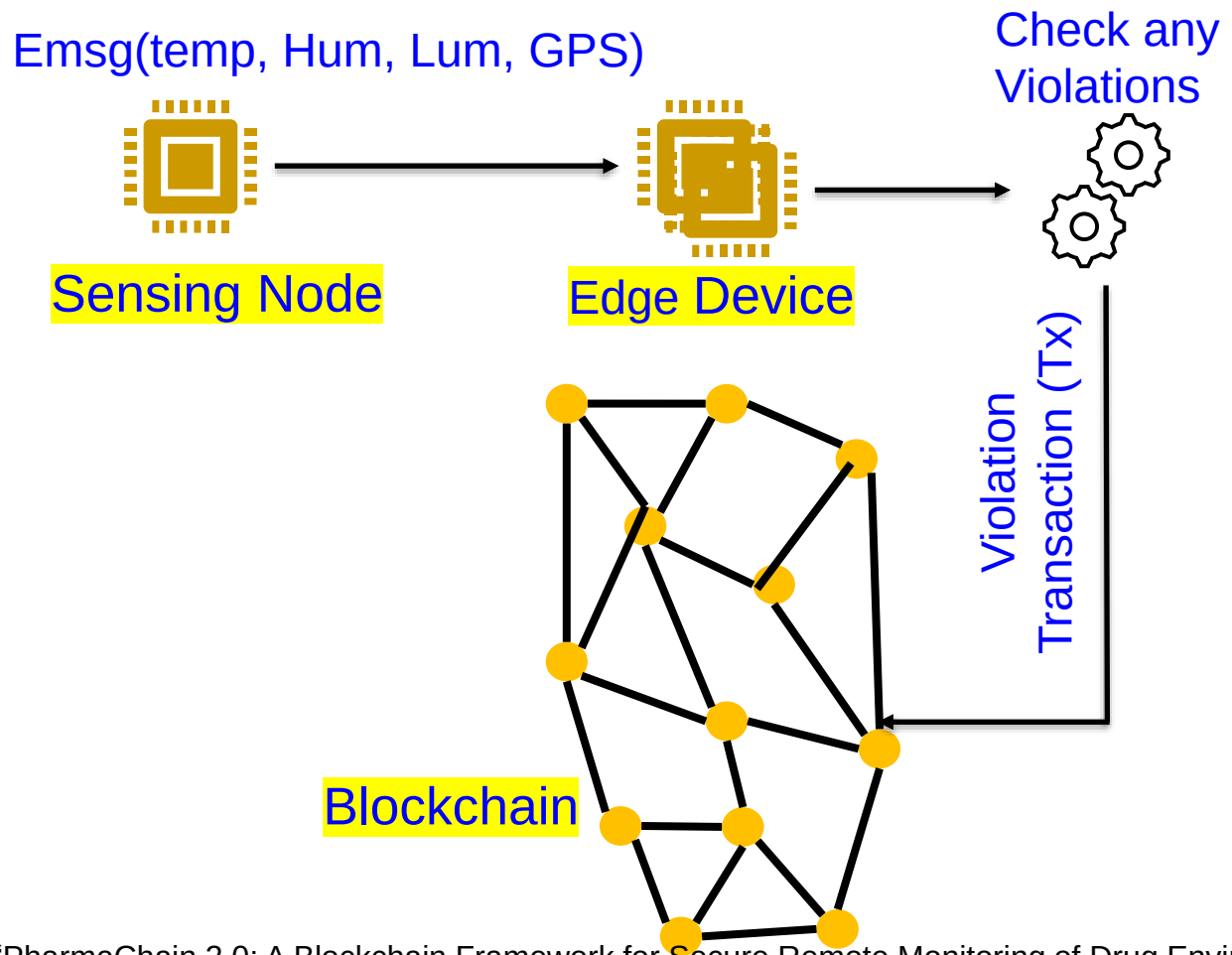
Input: Temperature, Humidity, Luminosity and GPS Position data from End node

Output: Violation data transaction published to blockchain network and cloud layer

1: End node E prepares a message E_{msg} with all the environmental parameters Temperature (temp), Humidity (hum), Luminosity (lum) and GPS position data(gps)
2: Prepared message is published to the topic τ of edge device using light weight pub-sub protocol
3: E.Publish(τ,E_{msg}(temp,Hum,lum,GPS))
4: Edge device E_e consumes the messages sent by the end nodes
5: E_e.consume(τ)

Phase 1 – Edge Device Processing

6: **procedure** EDGE DEVICE PROCESSING
7: **for** Every message E_{msg} **do**
8: Check the pre-defined conditions on Temperature, Humidity, Luminosity
9: **if** Any Violation Detected **then**
10: Publish violation data V_E to both cloud
11: E_e.Publish(V_E)
12: Prepare and send transaction to blockchain network
13: Tx ← E_e.prepareTransaction(V_E)
14: E_e.generateTransaction(Tx)
15: **end if**
16: **end for**
17: **end procedure**



Source: A. K. Bapatla, **S. P. Mohanty**, E. Kougianos, and D. Puthal, "PharmaChain 2.0: A Blockchain Framework for Secure Remote Monitoring of Drug Environmental Parameters in Pharmaceutical Cold Supply Chain", in *Proceedings of the IEEE International Symposium on Smart Electronic Systems (iSES)*, 2022, pp. Accepted.

Proposed Algorithm – Log Generation

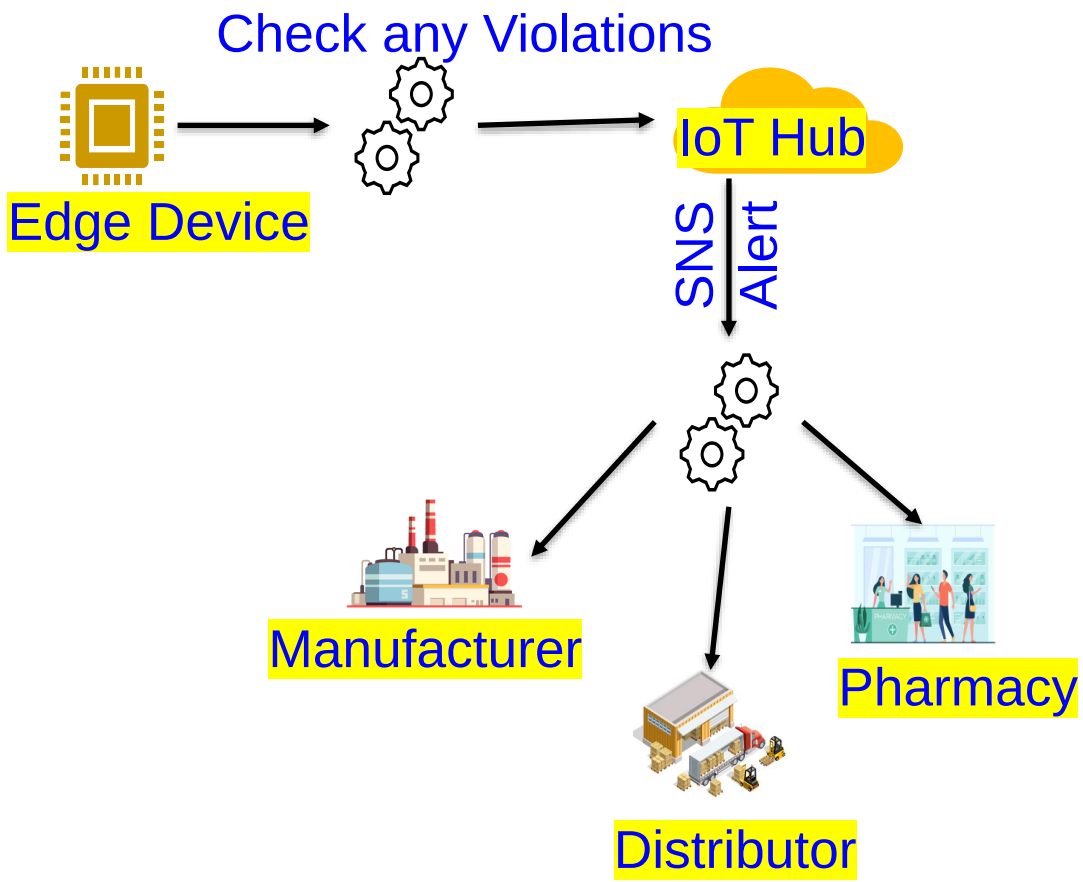
Phase 2 – Cloud Layer Processing

procedure CLOUD LAYER PROCESSING
  for Every Violation Data V_E received **do**
    Consume the message
    IoTHub.consume(V_E)
    Generate an alert using SNS (Simple Notification Service) to the registered entities
    SNS.generateAlert(V_E)
  end for
end procedure

Phase 3 – Blockchain Layer Processing

procedure BLOCKCHAIN LAYER PROCESSING
  Generated transaction is received into unconfirmed transactions pool (UTx)
  UTx.append(Tx)
  Miner picks transaction from UTx pool and creates a block
  Mining performed based on PoAh consensus protocol
  New block is added to the chain at all the participating nodes in the network creating an immutable violation data log

end procedure

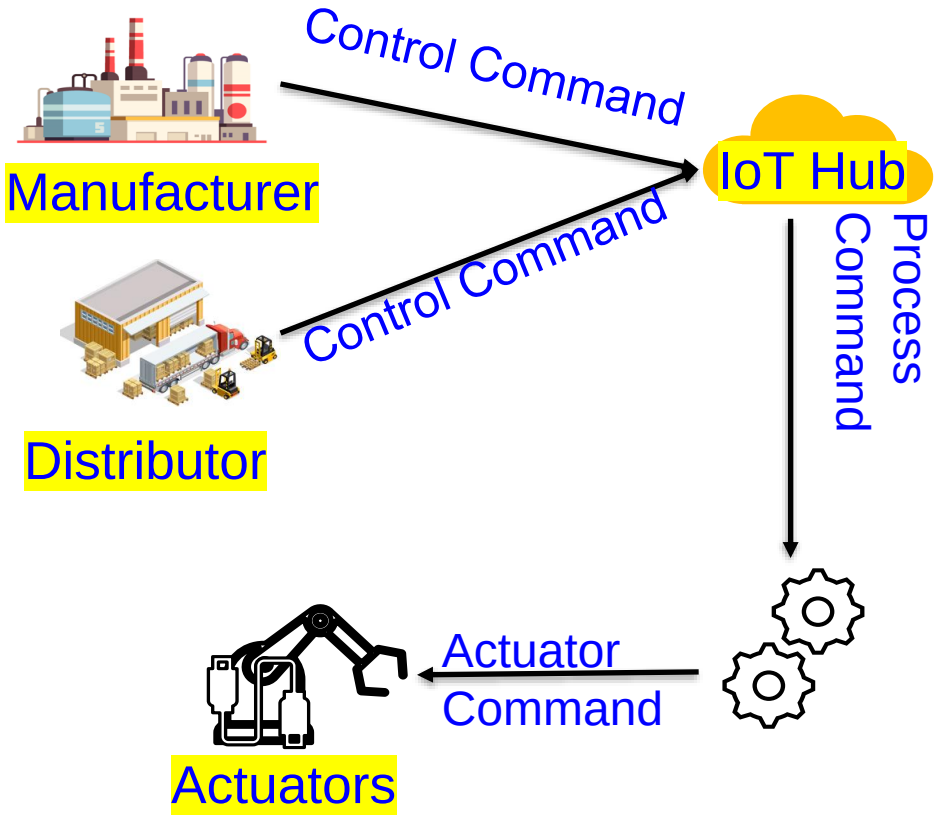


Source: A. K. Bapatla, **S. P. Mohanty**, E. Kougianos, and D. Puthal, "PharmaChain 2.0: A Blockchain Framework for Secure Remote Monitoring of Drug Environmental Parameters in Pharmaceutical Cold Supply Chain", in *Proceedings of the IEEE International Symposium on Smart Electronic Systems (iSES)*, 2022, pp. Accepted.

Proposed Algorithm- Control Algorithm

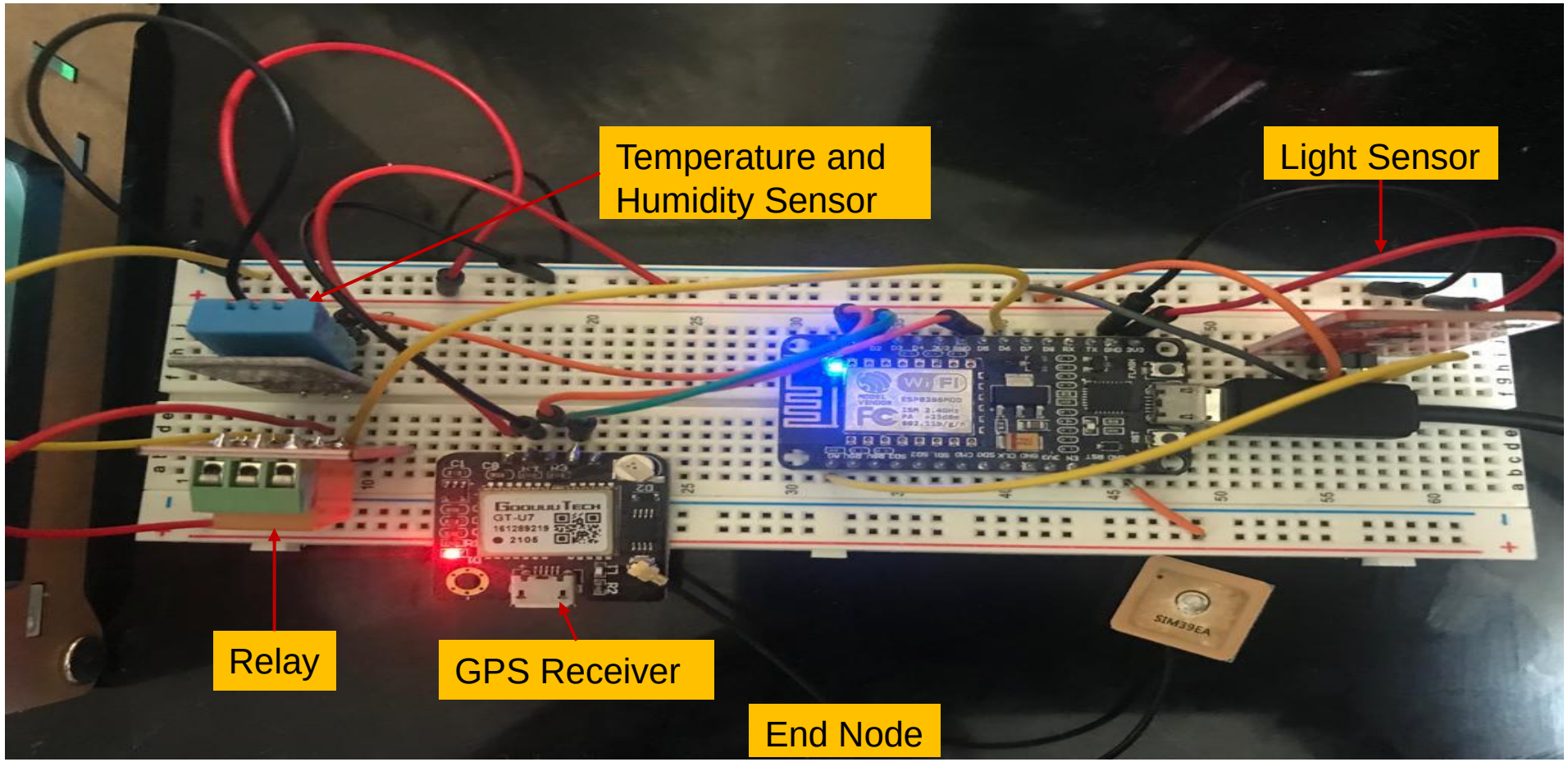
Algorithm 2 Proposed Control Algorithm For PharmaChain 2.0

1: **for** Each violation alert received **do**
2: Alert is reviewed by the responsible entity in the cold supply chain network
3: Control command CC_e for actuator is prepared by the entity
4: $CC_e \leftarrow$ Entity.prepareCommand(Control Instructions)
5: Control command is published to the cloud layer
6: Entity.publish(CC_e)
7: Cloud Layer processes the command and prepares control instructions for end node
8: $CC_e^+ \leftarrow$ IoTHub.process(CC_e)
9: Cloud layer published the processed control command to the edge devices
10: IoTHub.publish(CC_e^+)
11: Edge devices will send control instructions to the corresponding end devices
12: **for** Received Control Instructions by End Node e **do**
13: e.consume(CC_e^+))
14: Process and turn ON/OFF the actuators
15: e.process(CC_e^+))
16: **end for**
17: **end for**



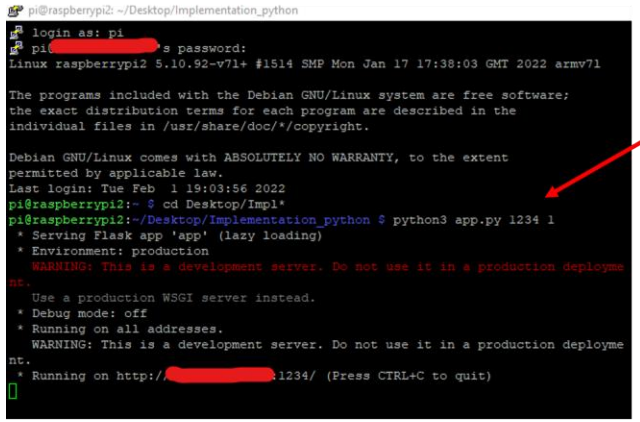
Source: A. K. Bapatla, **S. P. Mohanty**, E. Kougianos, and D. Puthal, "PharmaChain 2.0: A Blockchain Framework for Secure Remote Monitoring of Drug Environmental Parameters in Pharmaceutical Cold Supply Chain", in *Proceedings of the IEEE International Symposium on Smart Electronic Systems (iSES)*, 2022, pp. Accepted.

Implemented Sensing Node



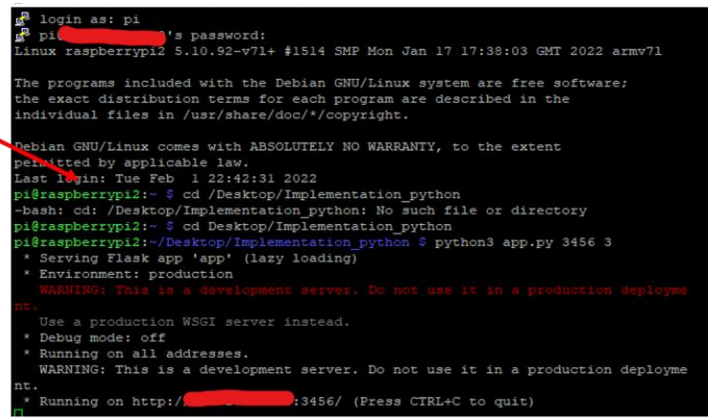
Source: A. K. Bapatla, **S. P. Mohanty**, E. Kougianos, and D. Puthal, “PharmaChain 2.0: A Blockchain Framework for Secure Remote Monitoring of Drug Environmental Parameters in Pharmaceutical Cold Supply Chain”, in *Proceedings of the IEEE International Symposium on Smart Electronic Systems (iSES)*, 2022, pp. Accepted.

Implementation and Validation

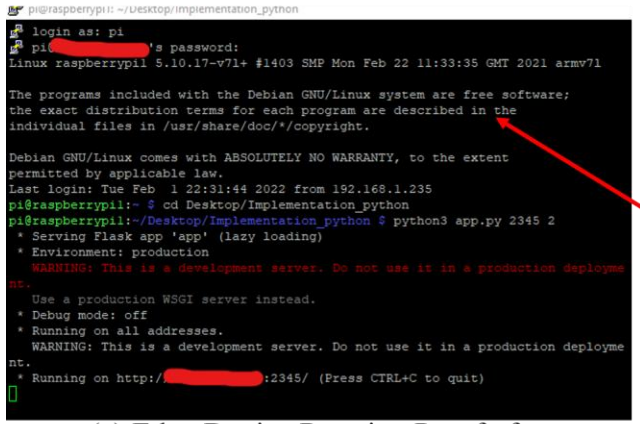


(a) Edge Device Running Proof of Authentication Based Blockchain

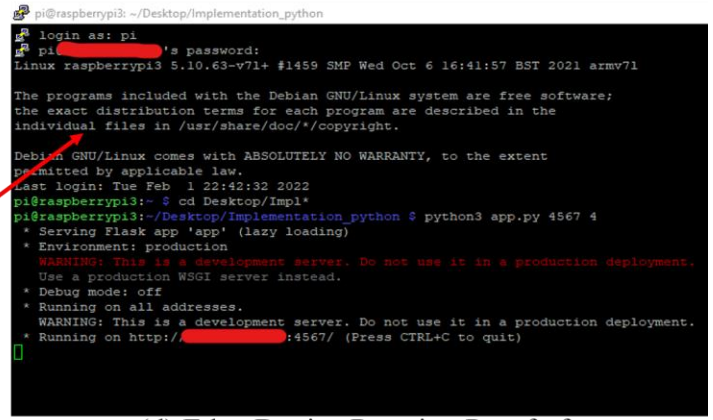
(e) Implemented Four Node Prototype for PharmaChain 2.0



(b) Edge Device Running Proof of Authentication Based Blockchain



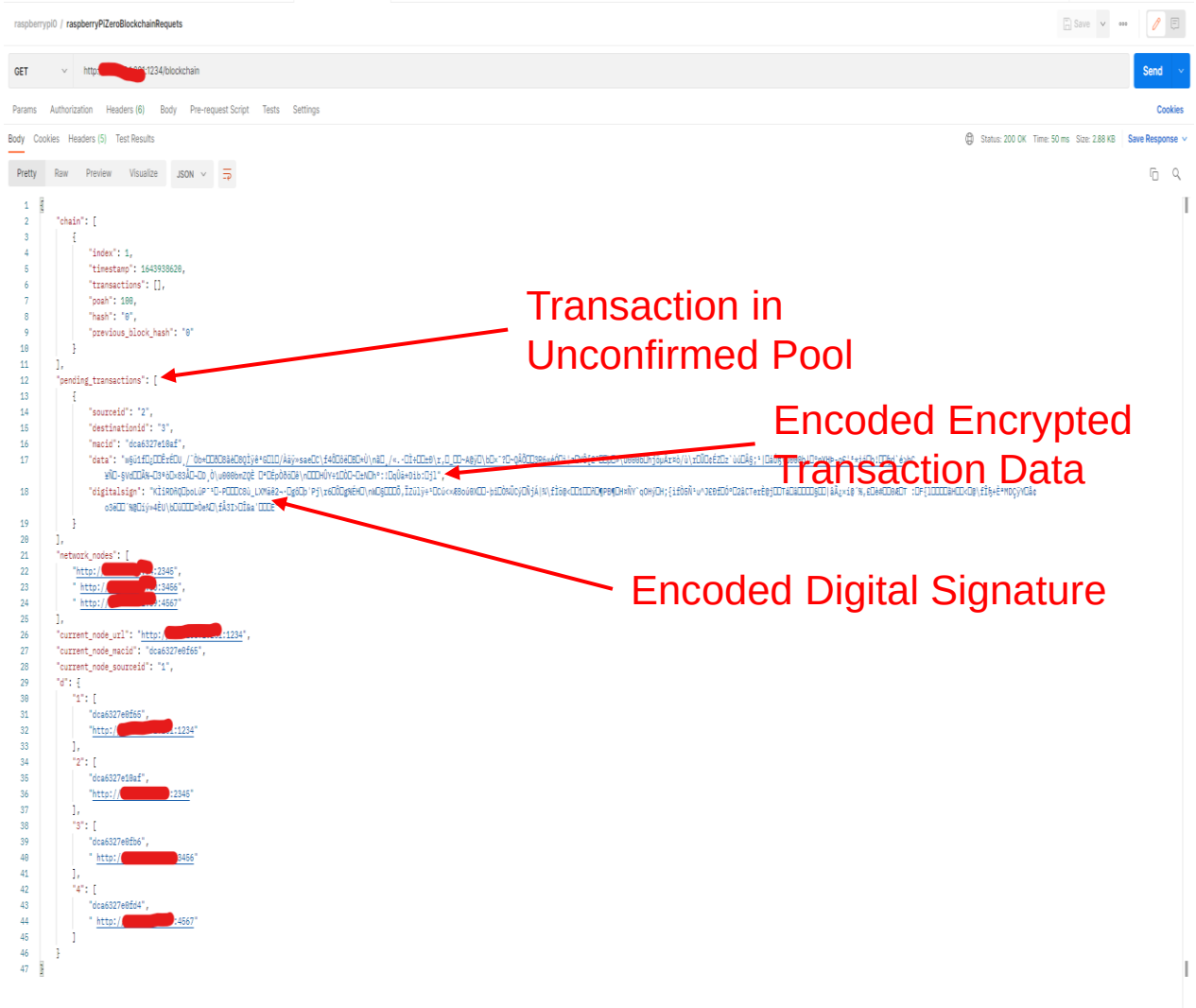
(c) Edge Device Running Proof of Authentication Based Blockchain

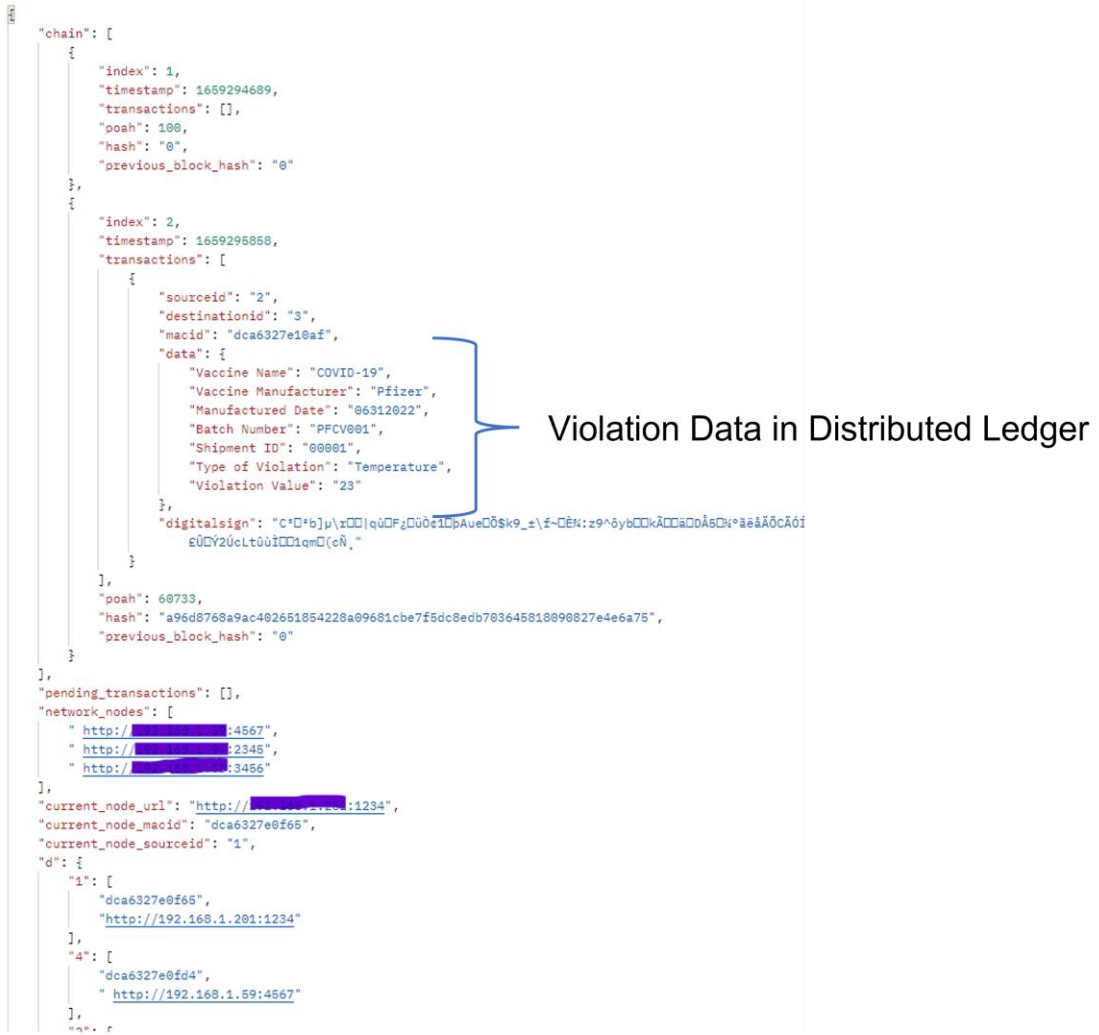


(d) Edge Device Running Proof of Authentication Based Blockchain

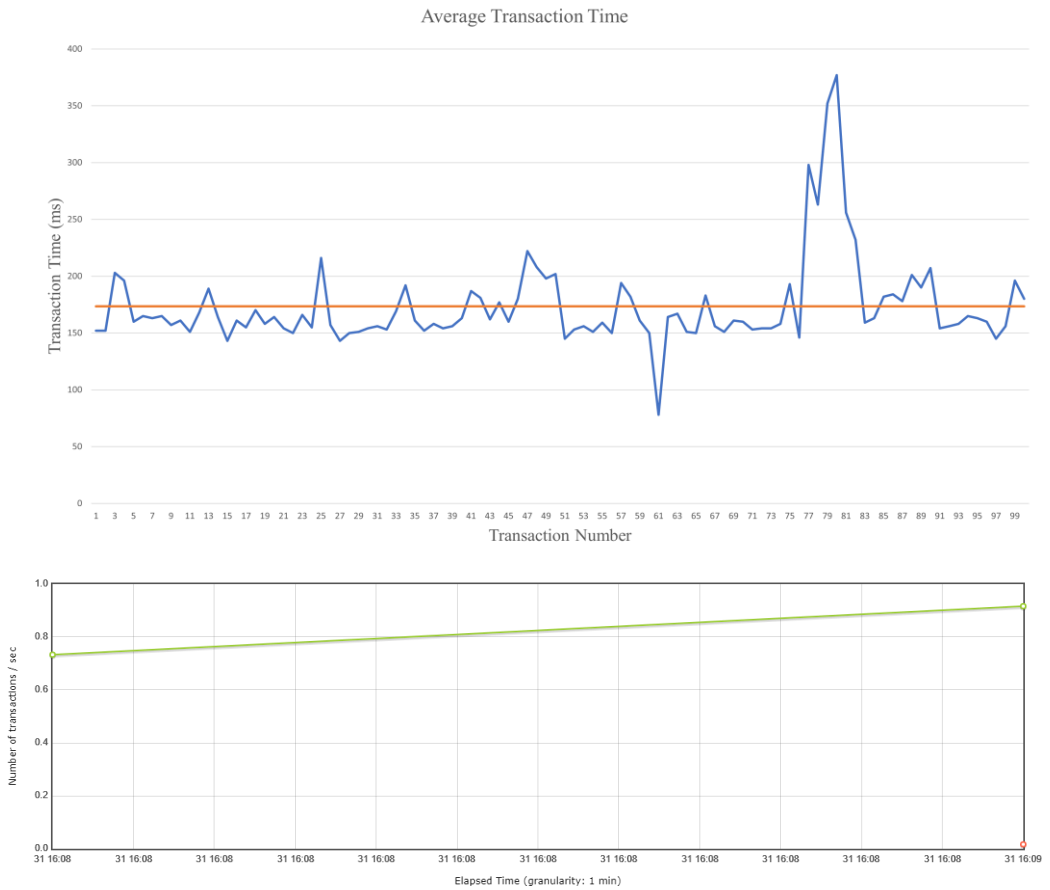
- Two nodes act as a miner nodes which are responsible for creating blocks from the unconfirmed

Pharmachain 2.0 Validation



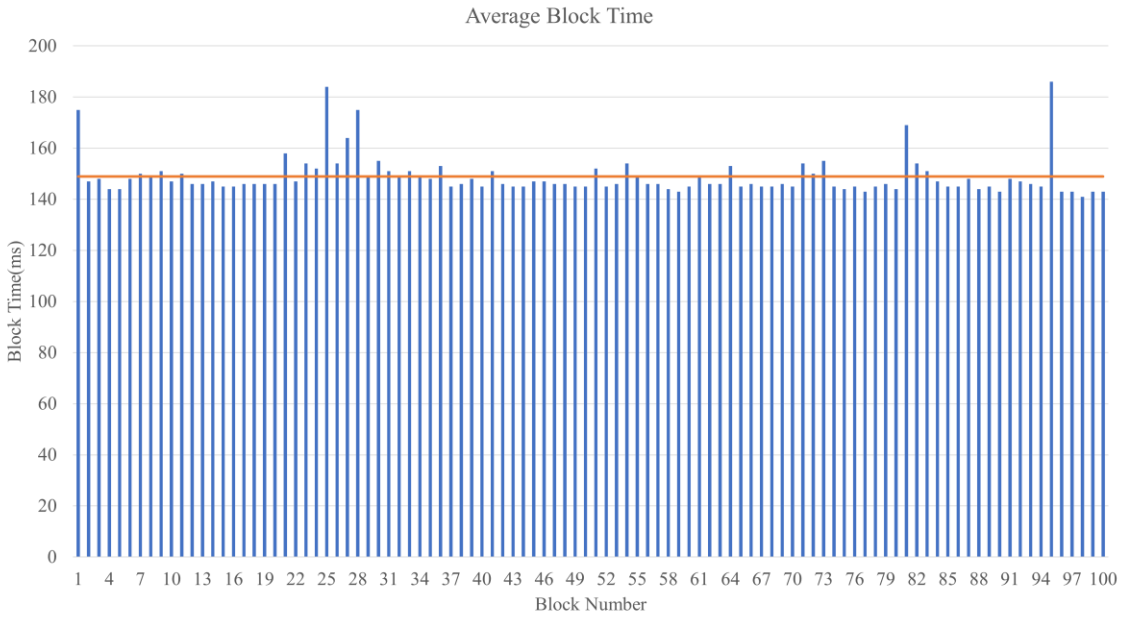


Testbed Evaluation



	Transaction Time	Block Time	Total Time
PharmaChain 2.0	173.39ms	148.89 ms	322.28ms

Analysis Summary of PharmaChain 2.0



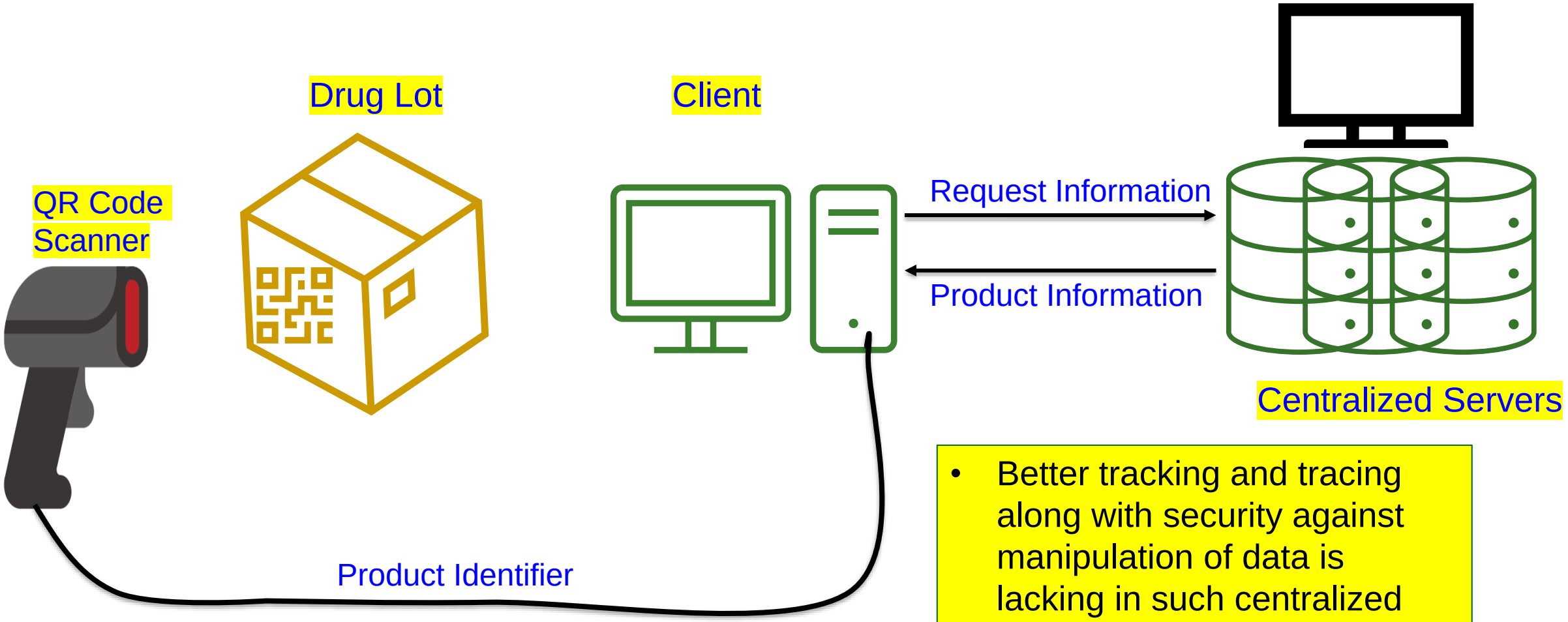
Comparative Analysis with Existing Solutions

Comparison of Proposed PharmaChain 2.0 solution with Existing Solutions					
Features	**Blockchain**	**Consensus Protocol**	**Openness**	**IoT Friendly Consensus**	**Average Time**
CryptoCargo [15]	Ethereum	Proof-of-Work (PoW)	Public	No	43.36 sec
PharmaChain [9]	Ethereum	Proof-of-Authority (PoA)	Private	No	5.6 sec
Current Paper (PharmaChain 2.0)	PoAh Consensus Based Blockchain	Proof-of-Authentication (PoAh)	Private	Yes	322.28ms

Ease of Integrating Blockchain in Pharmaceutical Supply Chain

PharmaChain 3.0: Blockchain Integrated Efficient QR Code Mechanism for Pharmaceutical Supply Chain

Typical QR Code System



- Better tracking and tracing along with security against manipulation of data is lacking in such centralized systems

Issues Traditional Tracking

- Removing Centralized Authorities
- Response Times
- Consumer accessibility of Drug Information
- Data Security
- Data Integrity
- No End-to-End Transparency
- Fragmentation of Information

Novel Contributions

- P2P network and consensus-based updates used in PharmaChain 3.0 remove the centralized entities and need for centralized databases for retrieving drug information.
- Shared ledger proposed in PharmaChain 3.0 provides high availability of data providing low latency for data retrieval.
- With the proposed QR Code integrated with the Blockchain mechanism, various drug information along with track and trace information can be stored in a single place and can be accessed using a single QR Code scan.
- Due to the immutability nature of blockchain, various threats like data security and unauthorized modifications are eliminated.

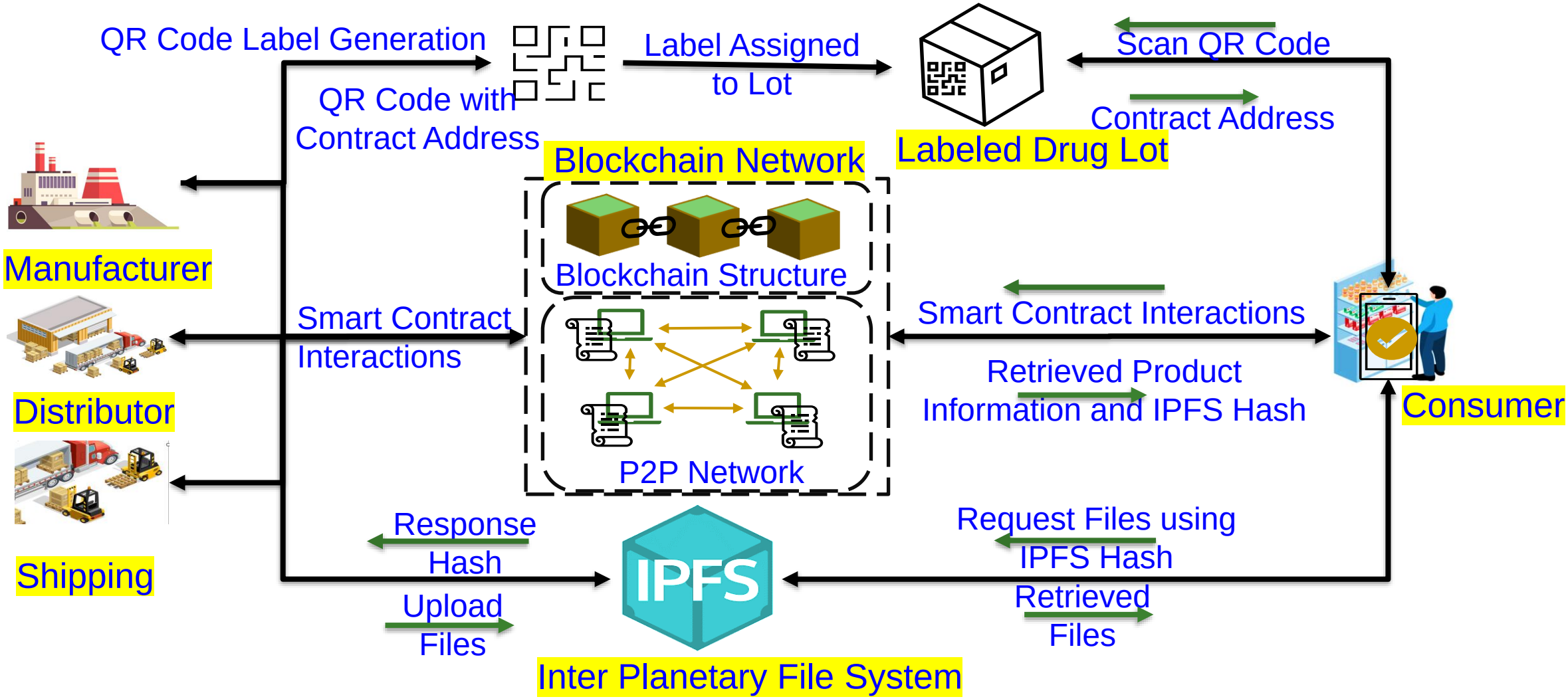
PharmaChain 2.0 Versus PharmaChain 3.0

PharmaChain 2.0	PharmaChain 3.0
PoAh Consensus Based Blockchain, used for both Tracking & Tracing along with Monitoring and Controlling Temperature Excursions	Integrating Ethereum Blockchain into IoT Systems through QR Code Mechanism for easy Tracking and Tracing and Drug Information
Proof-of-Authentication (PoAh) with higher throughput	Proof-of-Stake (PoS) Consensus mechanism is used with lesser throughput than PoAh
Private Blockchain with only nodes participating from Entities	Private Blockchain with only nodes participating from Entities
IoT Friendly Consensus with less power and computations. Doesn't support smart Contracts.	P2P nodes are maintained by the entities and are computationally capable. No need for IoT-Friendly Consensus
The average transaction time is 322.28ms	The average Transaction time is 16.2 Sec
Less information storage capabilities	More information can be stored

Related Research

Proposed	Methods Used
Modum.io	Used Sensory tags MAC address for track and trace. Mainly looks at track and tracing.
A. Musamih et.al.	Smart contracts to track and trace. Integration using QR codes is not considered.
CryptoCargo	Similarly, considered track and tracing using blockchain but integration of QR codes is not implemented.
M. Dave et.al., P.Sylim et.al., D. Sinclair et.al.	Hyper ledger-based solution for track and tracing using Chain codes, however integration of IoT environment is not addressed.

Architectural Overview of PharmaChain 3.0



Proposed Algorithms

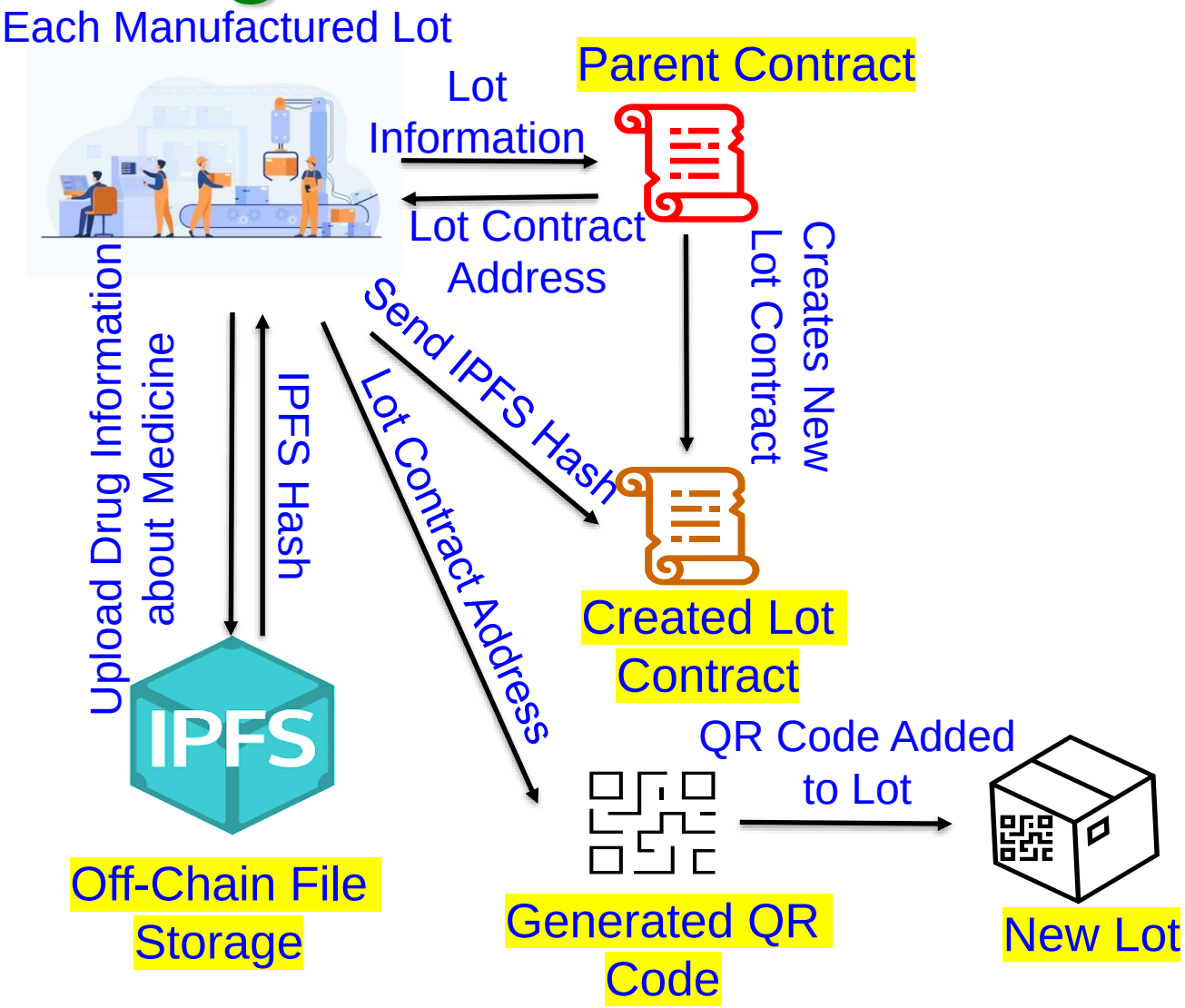
Algorithm 1 Data Upload and QR Code Generation Algorithm for Proposed PharmaChain 3.0

Input: Newly manufactured drug lot information files, shipping updates by entities in supply chain.

Output: Unique QR Code specific for newly manufactured lot and Immutable ledger of shipment updates.

Phase 1 – QR Code Generation

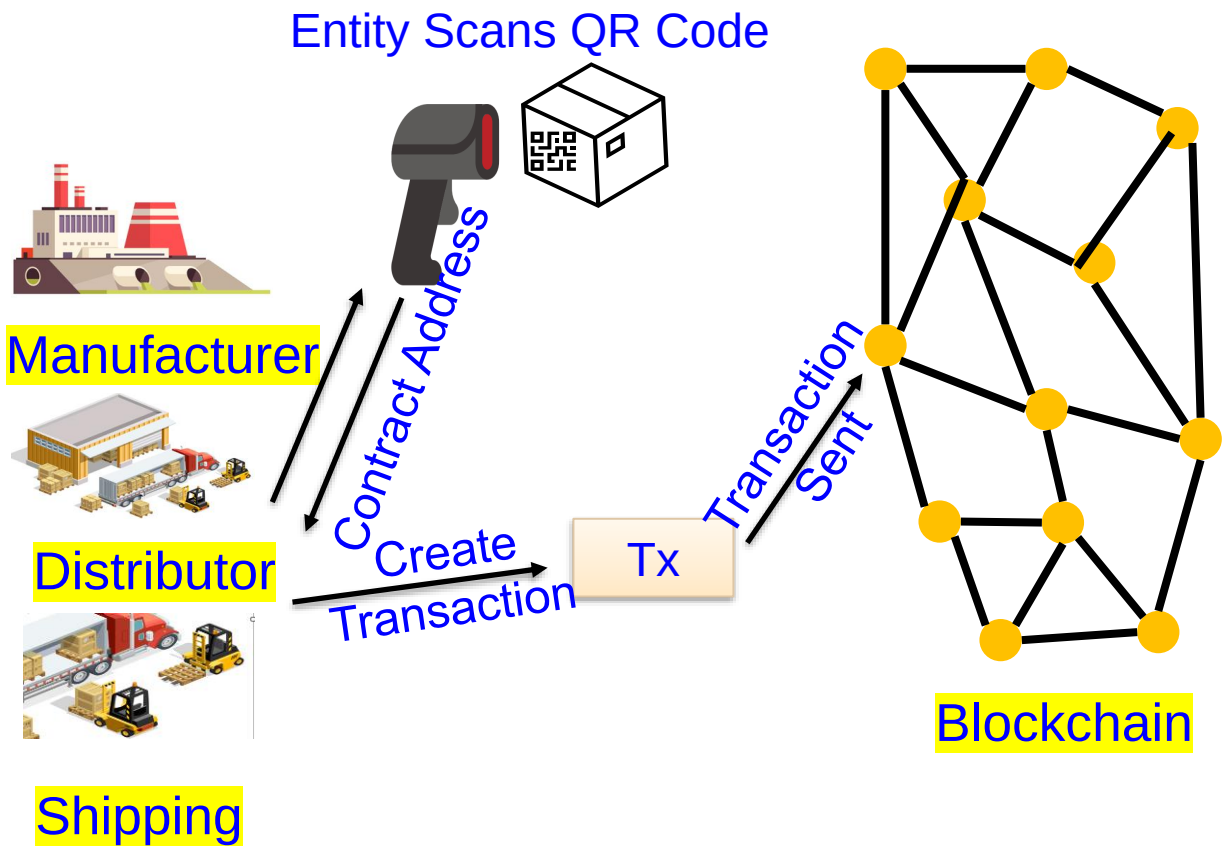
1: **procedure** QR CODE GENERATION
2: **for** Each Drug Lot Manufactured **do**
3: Lot specific contract is created by calling parent contract
4: $Contract_{lot} \leftarrow Contract_{partent}$.createNewLotContract()
5: Manufacturer uploads all required information about medicine on to IPFS system
6: **for** Each Data File **do**
7: Upload each individual file on IPFS
8: $IPFSHash_{file} \leftarrow$ IPFS.add(File)
9: Returned hash is then updated in the newly created drug lot smart contract
10: $Contract_{lot}$.addIPFSHash($IPFSHash_{file}$)
11: **end for**
12: Create a QR Code with newly created lot contract address information
13: QRCode.embed($Contract_{lot}$ Address)
14: Generated QR Code is assigned to the newly created drug lot
15: **end for**
16: **end procedure**



Proposed Algorithms

Phase 2 – Track and Trace Updates

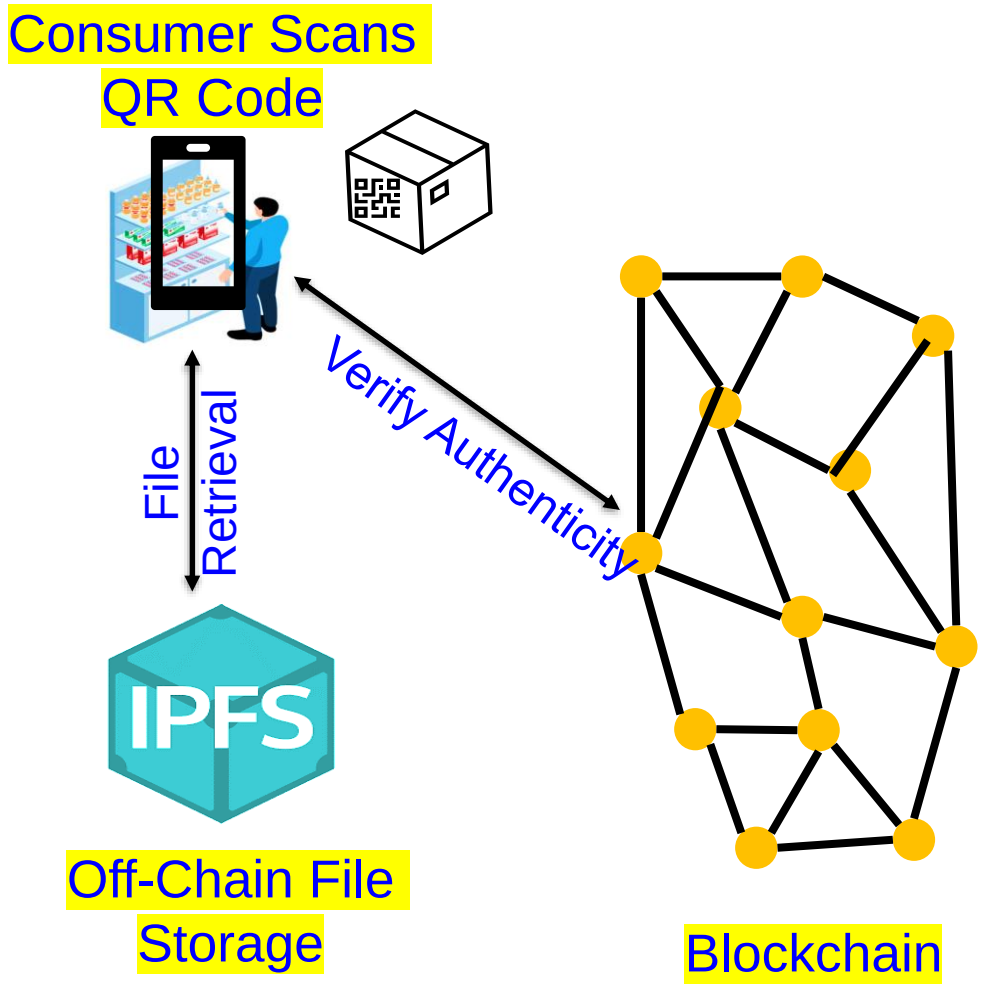
17: **procedure** TRACK AND TRACE UPDATES
18: **for** Each Shipment Update in Supply Chain **do**
19: Entity scans the QR Code to retrieve the lot contract address
20: $\text{Contract}_{lot} \leftarrow$ QRCodeScan()
21: New transaction is generated and contract call is done to update the information of lot
22: Newly generated transaction will be added to the unconfirmed transaction pool
23: Group of unconfirmed transaction will be picked by miner and a new block is created after performing consensus
24: New block is added at each and every node participating in the network creating immutable ledger of trail of ownership data
25: **end for**
26: **end procedure**



Proposed Algorithms

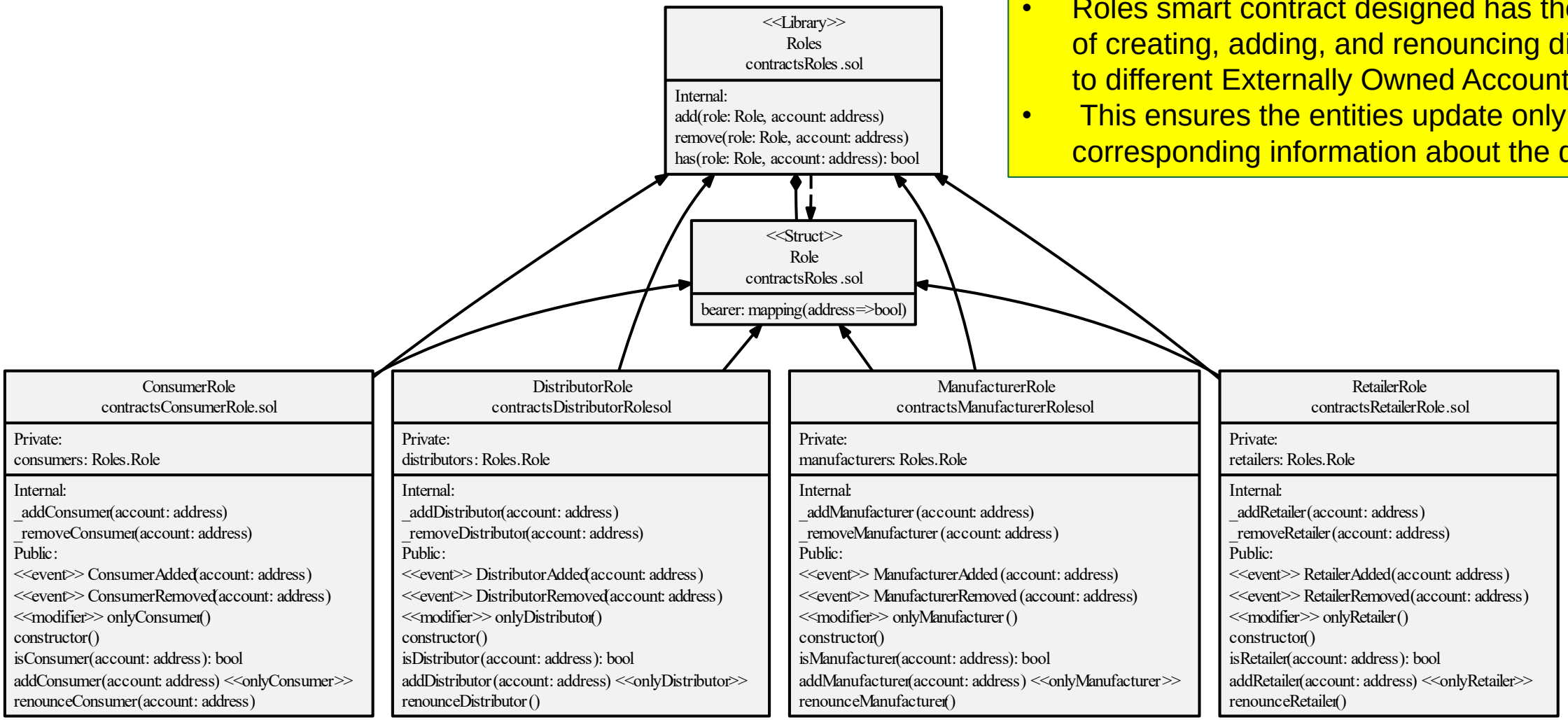
Algorithm 2 Algorithm for Drug Information Access and Authenticity Verification of Drug in Proposed PharmaChain 3.0

1: User scans the QR Code to get the lot contract address
2: $\text{Contract}_{lot} \leftarrow$ QRCodeScan()
3: IPFS hashes are retrieved from the lot contract call
4: $\text{IPFSHashes}_{file} \leftarrow \text{Contract}_{lot}$.getHashes()
5: **for** Each IPFS hash **do**
6: Retrieve each information file
7: FileData $\leftarrow$ IPFS.get(IPFSHash_{file})
8: **end for**
9: To verify authenticity, check the entities information updated in the smart contract
10: TrailInformation $\leftarrow \text{Contract}_{lot}$.getTrailInfromation()
11: Authenticity of product can be checked along with all required drug information can be accessed.



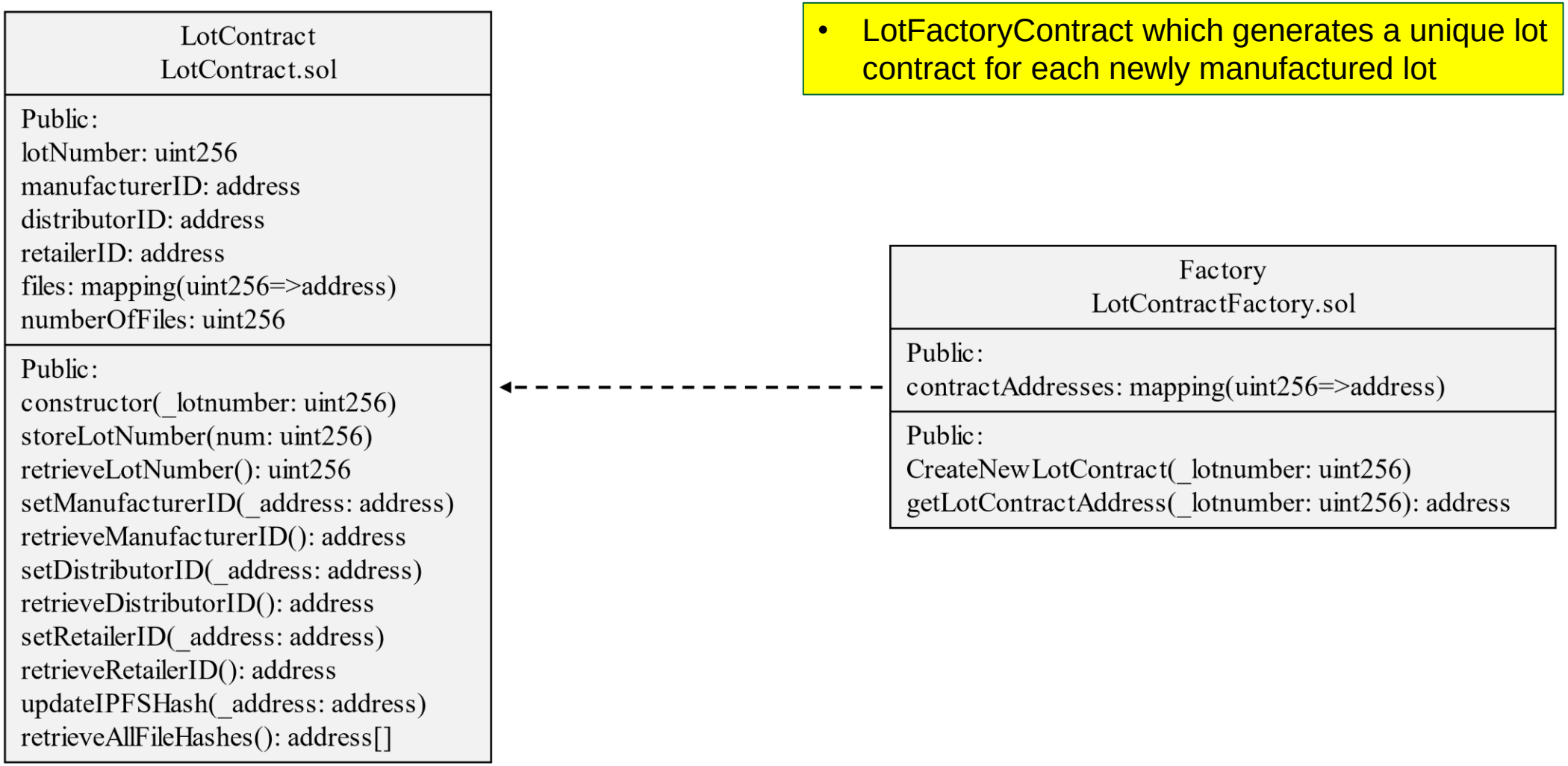
Role Based Access Control Mechanism

- Roles smart contract designed has the capability of creating, adding, and renouncing different roles to different Externally Owned Accounts (EOA).
- This ensures the entities update only the corresponding information about the drug



Factory Smart Contract

- LotFactoryContract which generates a unique lot contract for each newly manufactured lot



Implementation and Validation

- Ganache local blockchain is used to implement PharmaChain 3.0.
- Web3.js and Reactjs were used to develop the UI component.
- IPFS is used for providing distributed storage of large amounts of data.

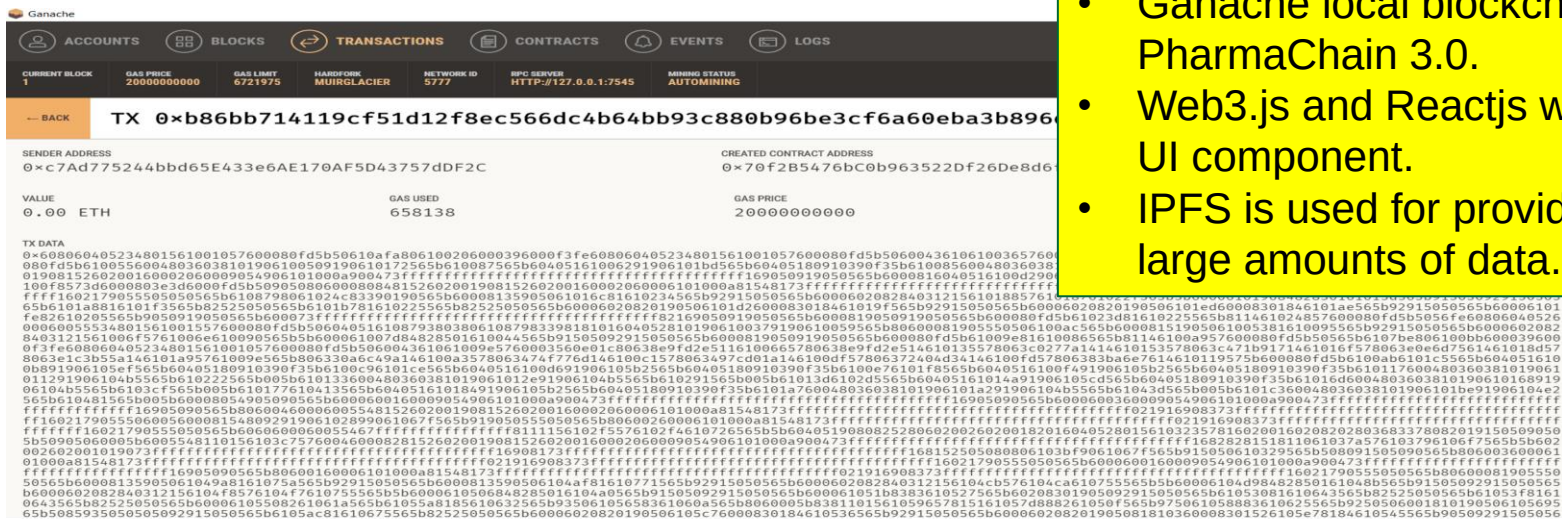
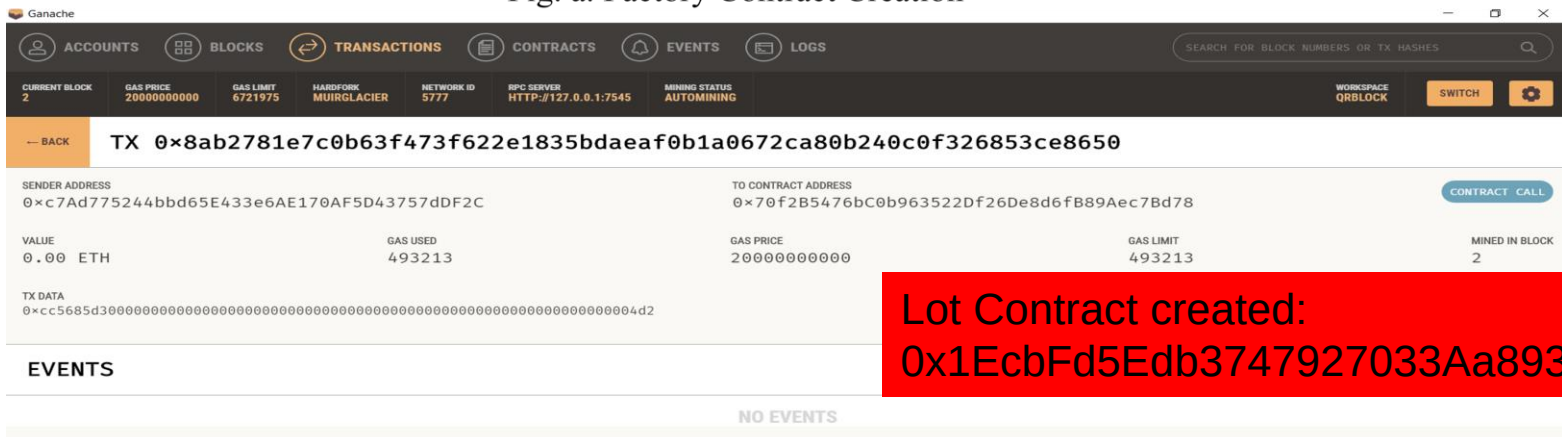


Fig. a. Factory Contract Creation



Lot Contract created:
0x1EcbFd5Edb3747927033Aa893416e4aD01DF0c6E

Fig. b. New Lot Contract Creation Transaction

Implementation and Validation

New Lot Contract Address Converted to QR Code for Labeling

Implementation and Validation

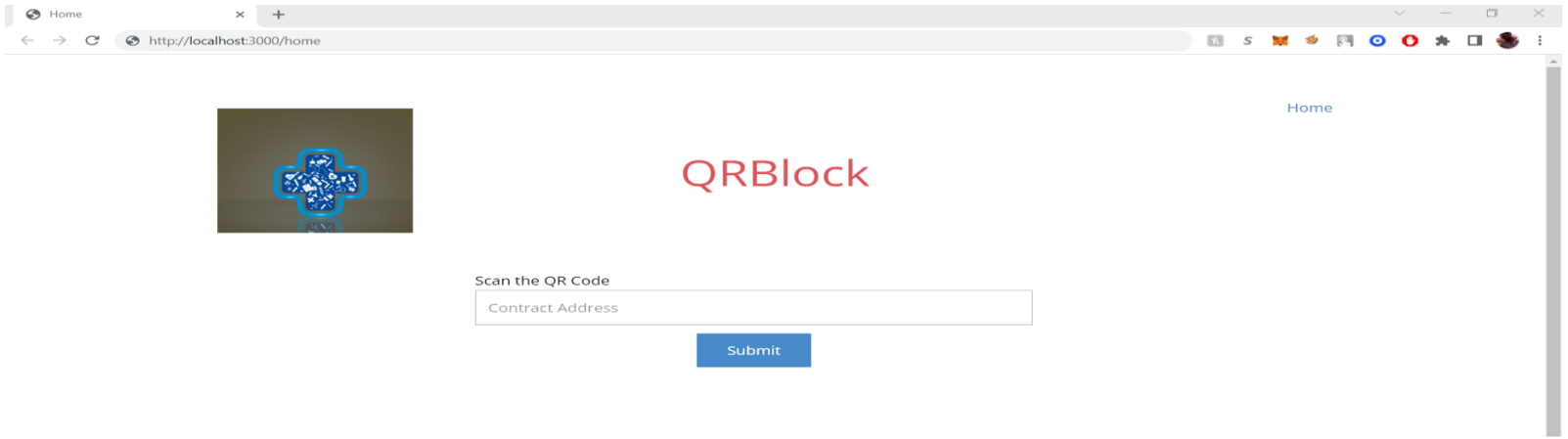


Fig. a. Scanning the QR Code to Get Contract Address

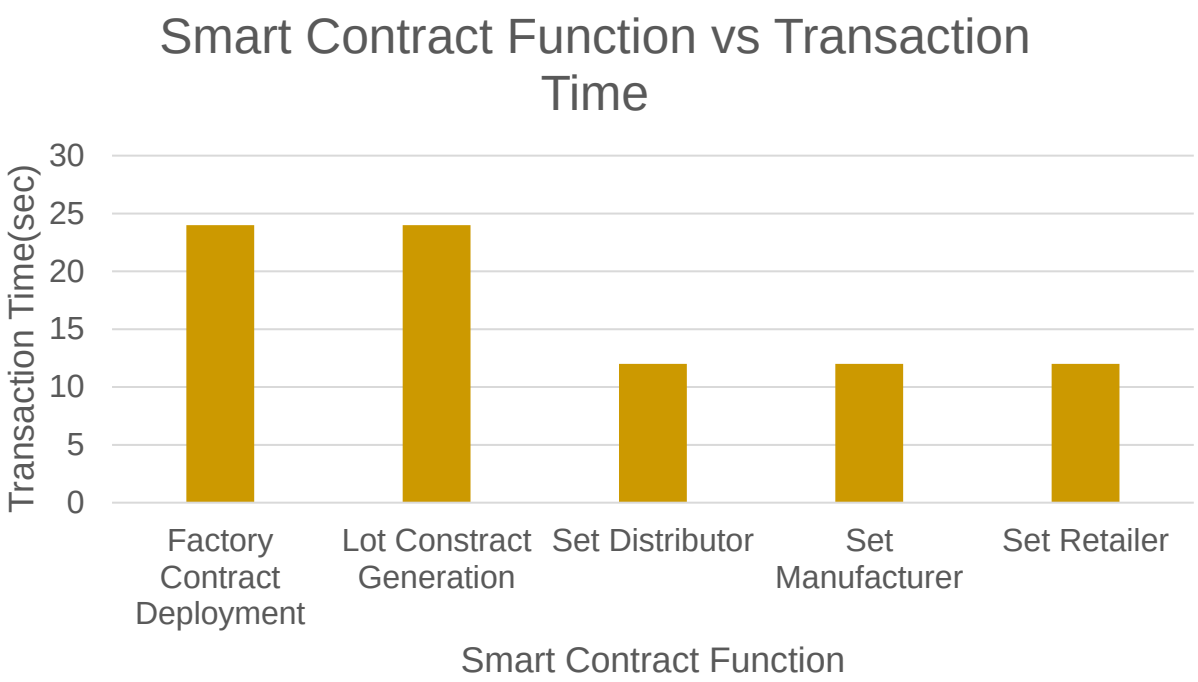
Fig. b. Fetching Drug Trail and IPFS Hashes

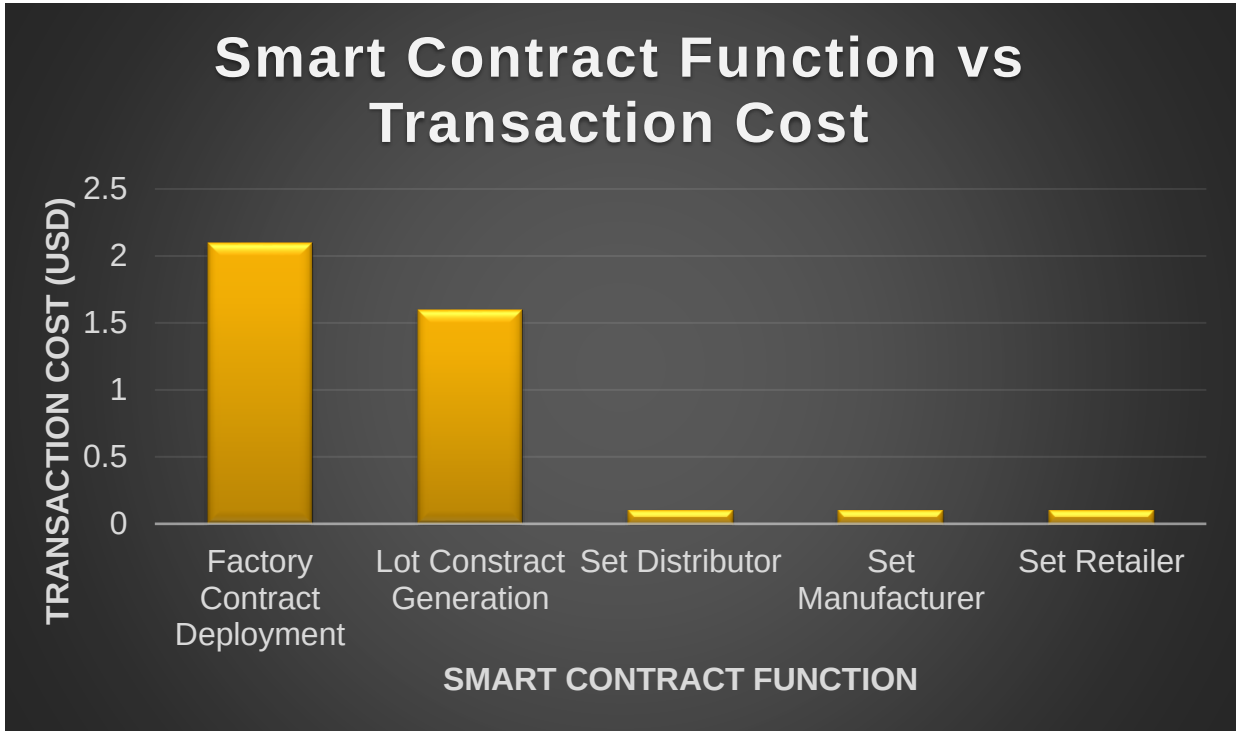
Security Analysis

- Threat 1: Counterfeit Drugs introduced into the supply chain by a malicious entity.
- Solution: Each transaction generated in the proposed PharmaChain 3.0 must be signed by the entity's private key before sending it to the blockchain.

- Threat 2: Data Integrity Attacks to manipulate data within the network
- Solution: Proposed PharmaChain 3.0 makes use of distributed shared ledger, each entity node participating in the network will have its copy of the ledger.

Timing and Cost Analysis





Comparative Analysis

	Blockchain	Consensus Mechanism	Less Computational Needs	Openness	QR Code Integrated	Storage	Handling large data
Crypto Cargo [11]	Ethereum	Proof-of-Work (PoW)	No	Public	No	On-Chain and Cloud	No
Kumar et.al. [9]	NA	NA	NA	NA	Yes	On-chain	No
PharmaChain [12]	Ethereum	Proof-of-Authority (PoA)	Yes	Private	No	On-Chain and cloud	No
PharmaChain 2.0	PoAh consensus-based blockchain	Proof-of-Authentication (PoAh)	Yes	Private	No	On-Chain and cloud	No
Current Solution (PharmaChain 3.0)	Ethereum	Proof-of-Stake (PoS)	Yes	Private	Yes	On-chain and off-Chain	Yes

Summary

- PharmaChain 3.0 presents a novel solution of embedding the smart contract addresses as the QR codes which will increase the accessibility of the tamper-proof information.
- This ensures the right medicines reach the consumer instead of counterfeits and increase consumer confidence.
- It also addresses the issue of uploading large data drug information files onto the blockchain by introducing an IPFS distributed storage system.
- Results from the analysis have shown that the proposed PharmaChain 3.0 is a feasible solution.

Future Research

- As future work, mechanisms to avoid the duplication of the QRCodes will be included.
- More user-friendly GUI will be provided in future work.
- Increasing efficiency in terms of cost and response times will be addressed in future work.
- Automating more complex interactions in the supply chain thereby reducing the latencies.

Thank You !!