

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

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Outline

- Counterfeit in HealthCare
- Blockchain Technology
- PharmaChain
- PharmaChain 2.0
- Working Flow of PharmaChain 2.0
- 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/>

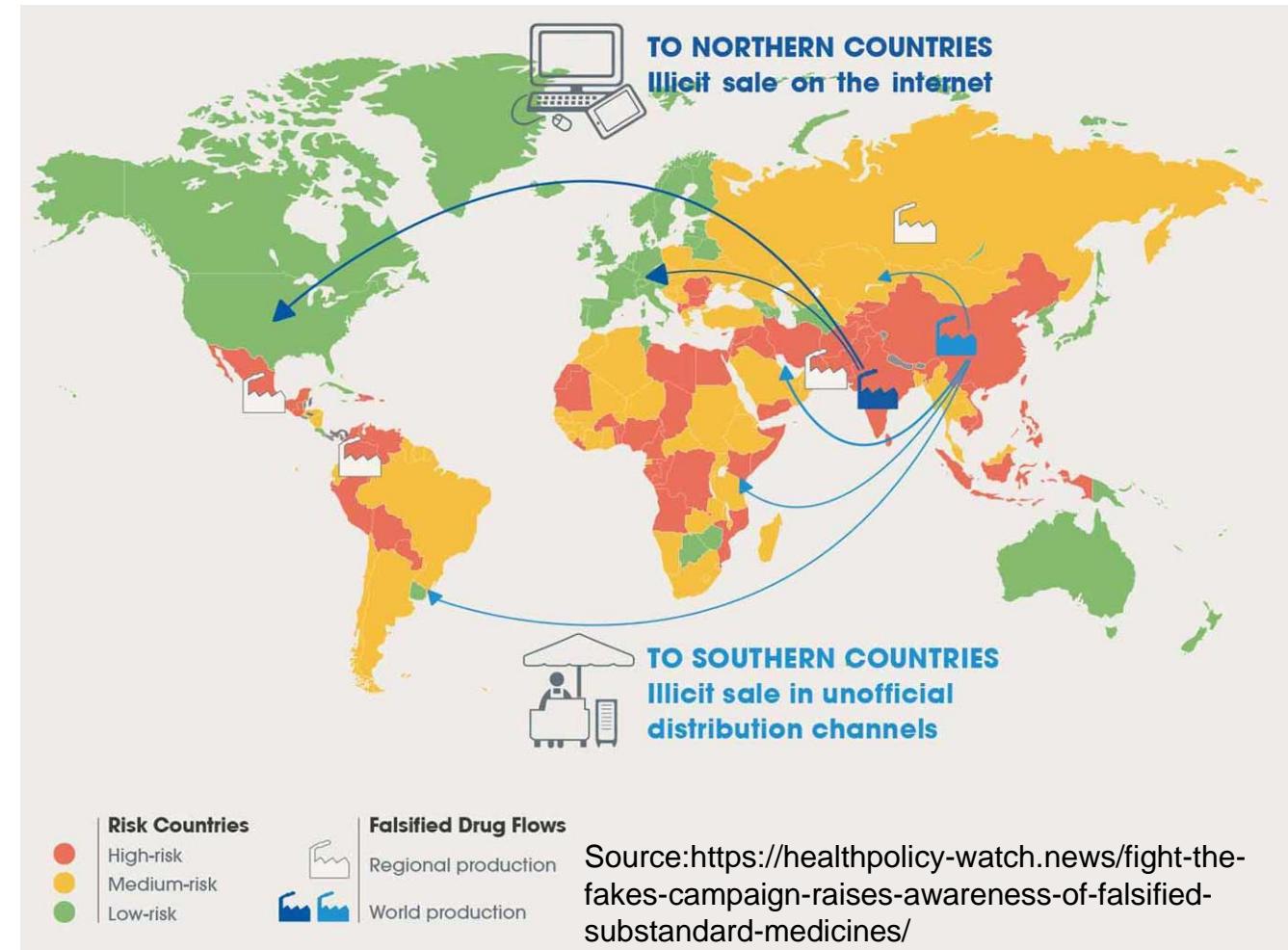
Fake Medicine - Serious Global Issue

- 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



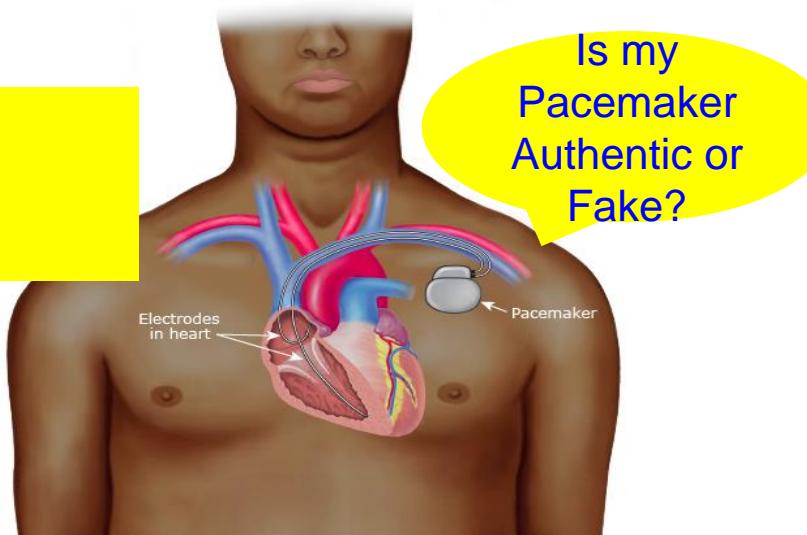
Authentic
An implantable medical device



Fake



Fake data by adversaries



- Consumers are always in dilemma
- Health Security issues



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



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>

11/12/2021
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 today.

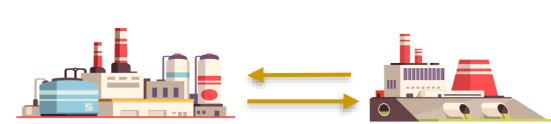
A federal grand jury in Beaumont has returned a three-count indictment charging nine individuals in a drug trafficking conspiracy in the Eastern District of Texas, announced Acting U.S. Attorney Nicholas J. Ganjei today.

ALEXANDRIA, 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.

PharmaChain - Counterfeit Free Pharmaceutical

Enterprise Resource Planning

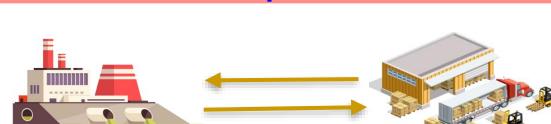
Transaction Ledger



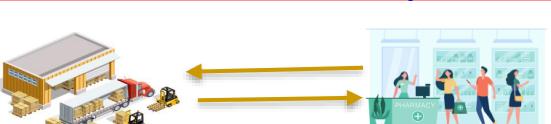
Blind Parties



Manufacturer places order and ingredients are supplied



Wholesaler places order from Manufacturer



Transfer of drugs from wholesaler to pharmacy



Prescribed medicines are dispensed to the consumer

Blockchain System

Blockchain Ledger



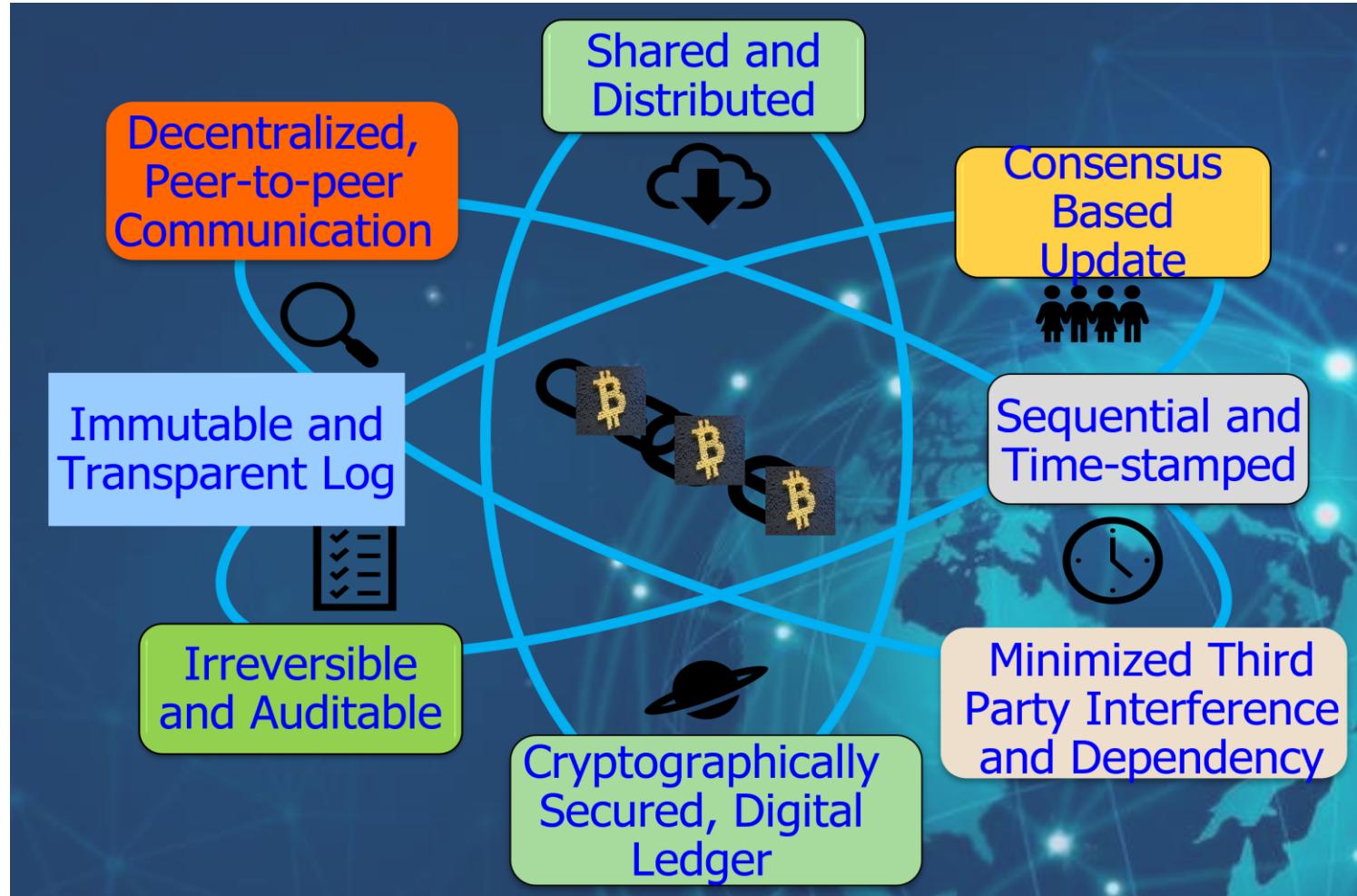
Transparent Ledger



Source: A. K. Bapatla, **S. P. Mohanty**, E. Kougiannos, 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



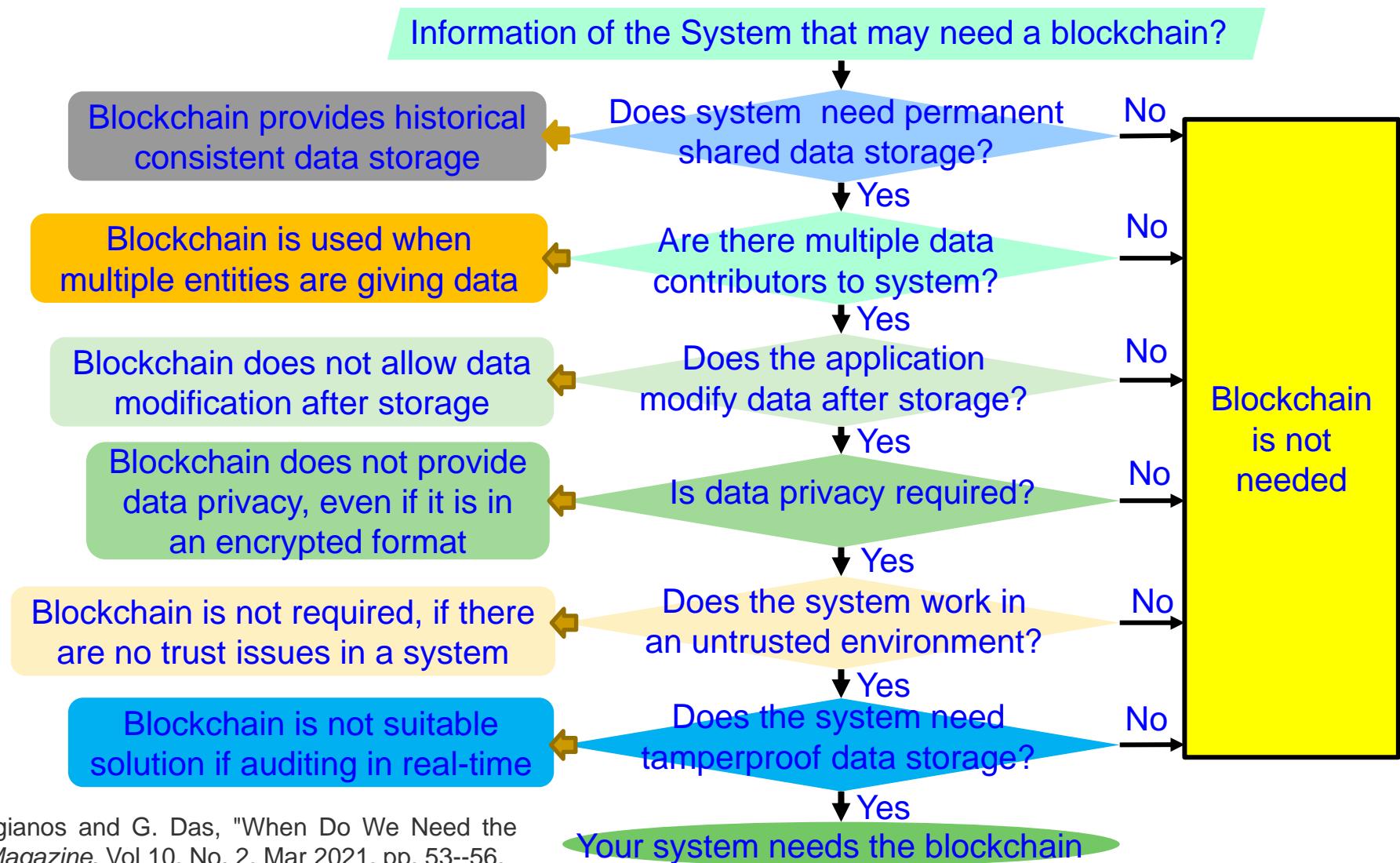
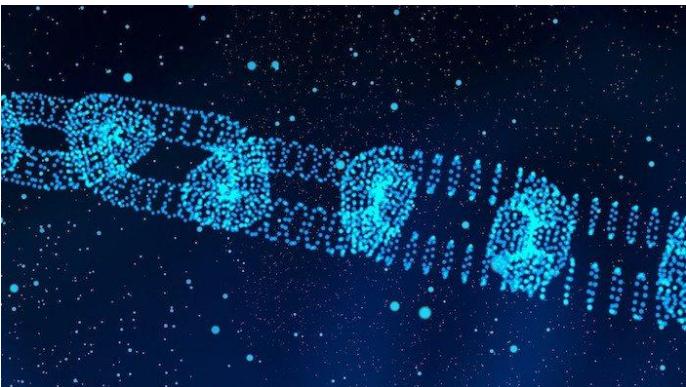
Technical Definition: A blockchain is a linked list that is built with hash pointers instead of regular pointers.

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.

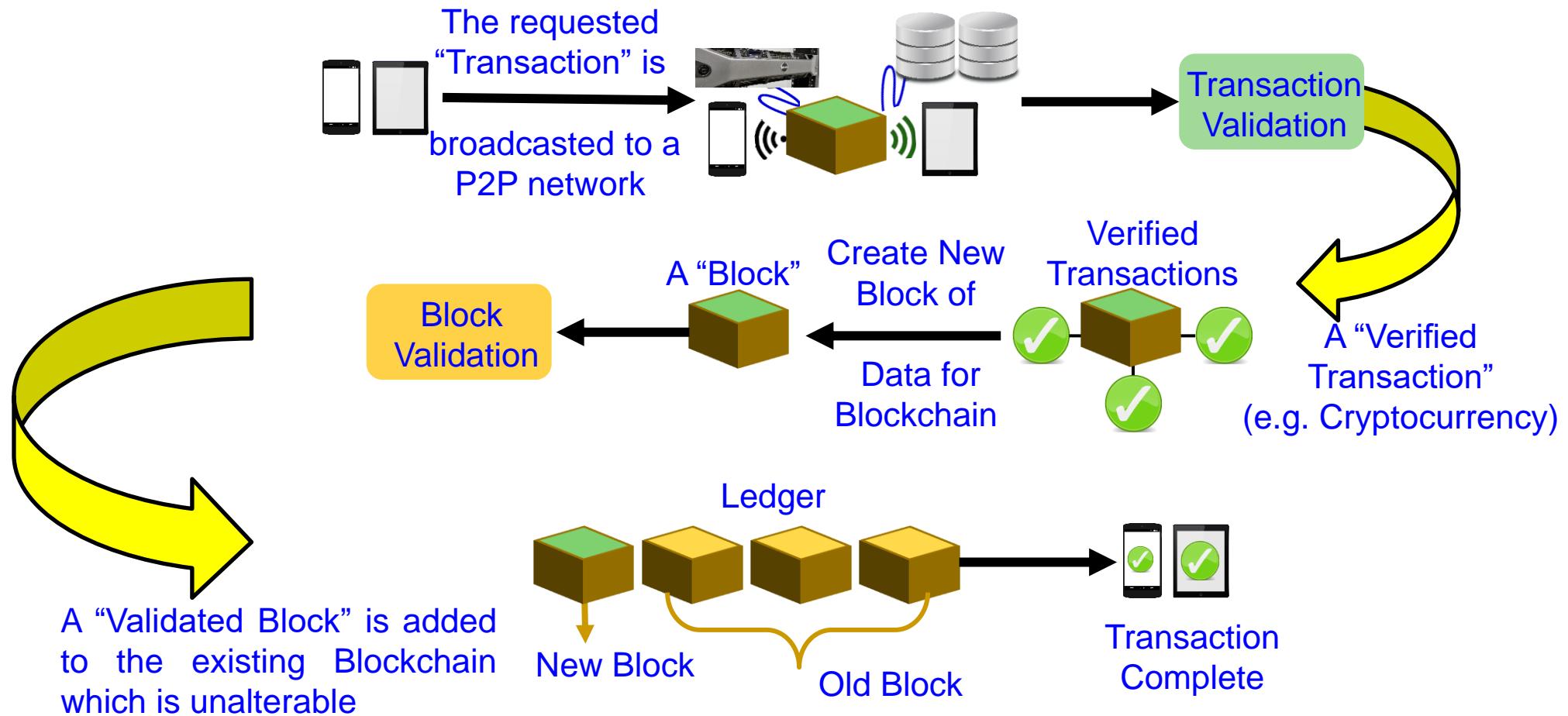
Source: D. Puthal, N. Malik, S. P. Mohanty, E. Kougianos, and C. Yang, "The Blockchain as a Decentralized Security Framework", *IEEE Consumer Electronics Magazine (CEM)*, Volume 7, Issue 2, March 2018, pp. 18--21.

When do You Need the Blockchain?



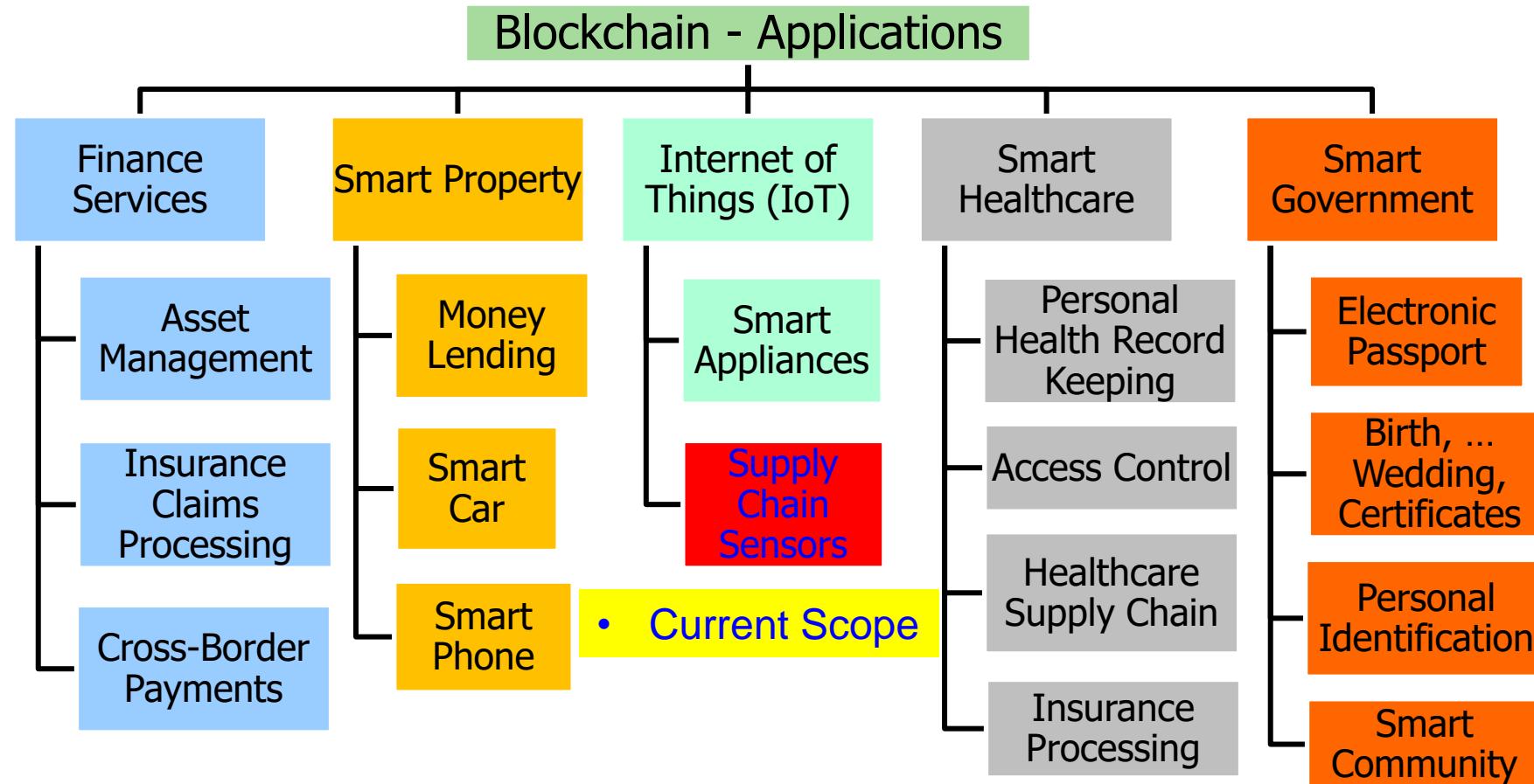
Source: D. Puthal, S. P. Mohanty, E. Kougianos and G. Das, "When Do We Need the Blockchain?," *IEEE Consumer Electronics Magazine*, Vol 10, No. 2, Mar 2021, pp. 53--56.

Blockchain Transaction Steps



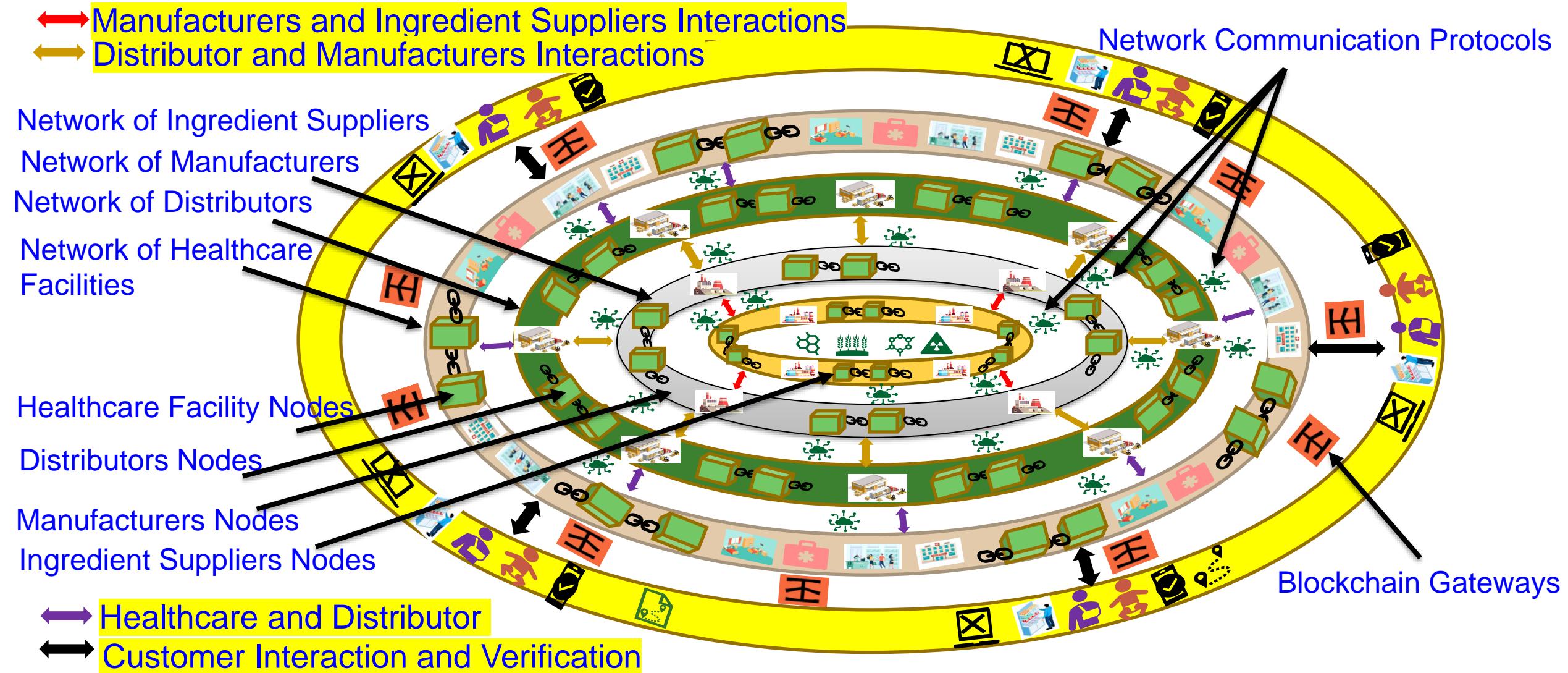
Source: Deepak Puthal, Nisha Malik, Saraju P. Mohanty, Elias Kougianos, and Gautam Das, "Everything you Wanted to Know about the Blockchain", *IEEE Consumer Electronics Magazine*, Vol. 8, No. 4, pp. 6--14, 2018.

Blockchain Applications



Source: D. Puthal, N. Malik, S. P. Mohanty, E. Koulianou, 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

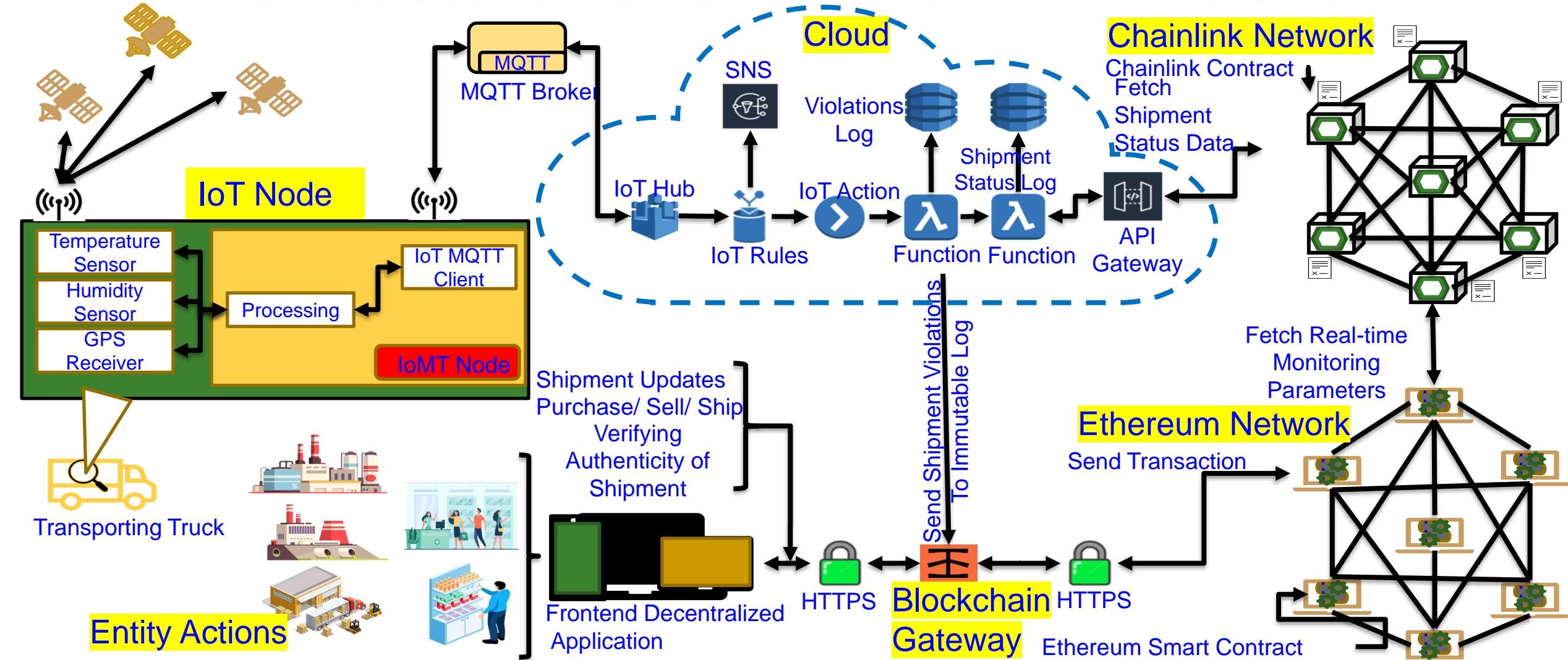


Source: Bapatla, A.K., et al.: PharmaChain: a blockchain to ensure counterfeit-free pharmaceutical supply chain. IET Netw. 1– 24 (2022). <https://doi.org/10.1049/ntw2.12041>

Our First Work to Transparent Pharmaceutical Supply Chains

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

Architectural Overview of PharmaChain

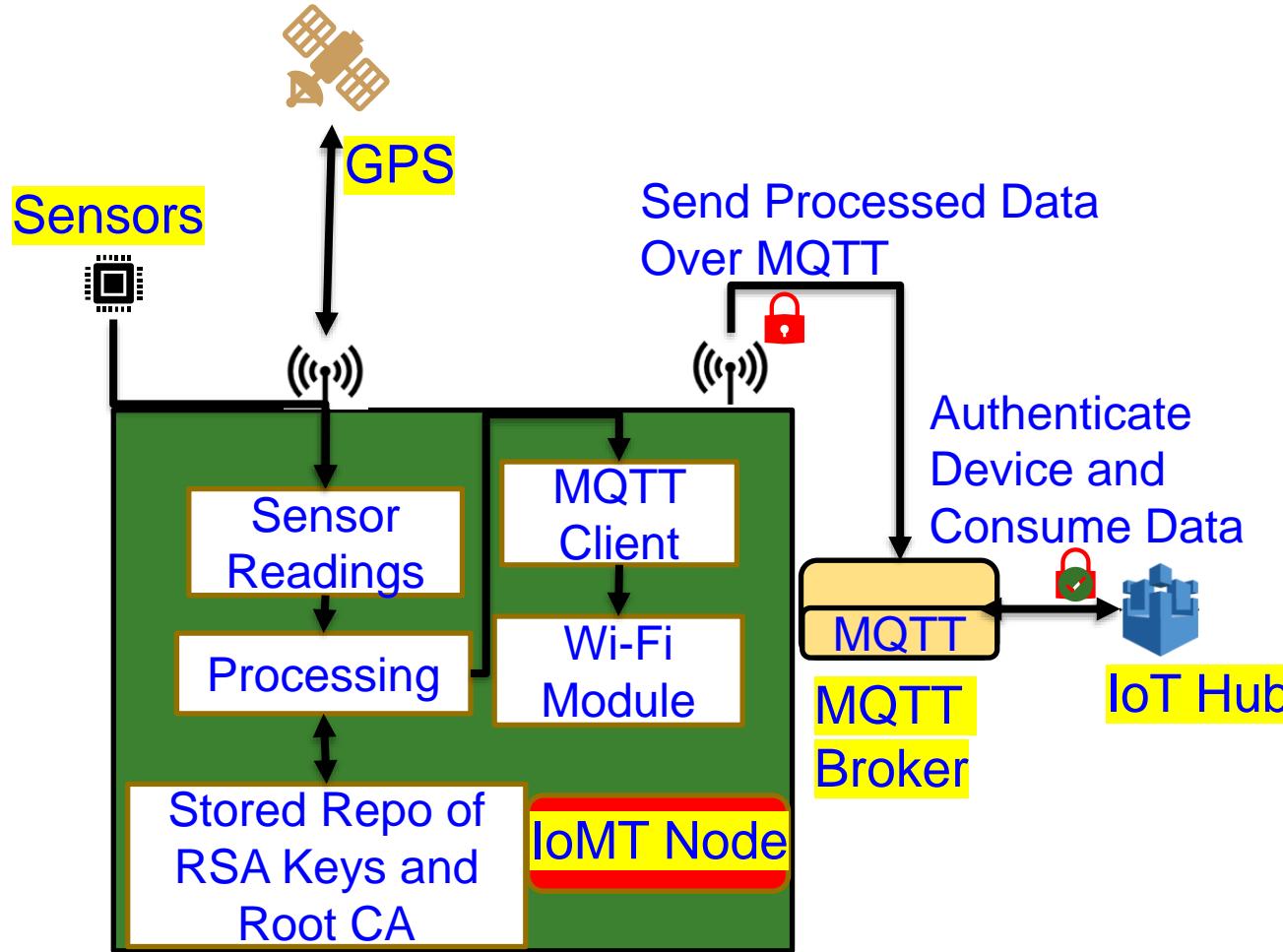


Source: A. K. Bapatla, **S. P. Mohanty**, E. Kougianos, D. Puthal, and A. Bapatla, "PharmaChain: A Blockchain to Ensure Counterfeit-Free Pharmaceutical Supply Chain", *IET Networks*, Vol. XX, No. YY, ZZ 2022, pp. Accepted on 24 June 2022, DOI: <https://doi.org/10.1049/ntw2.12041>. (Dataset for Research: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

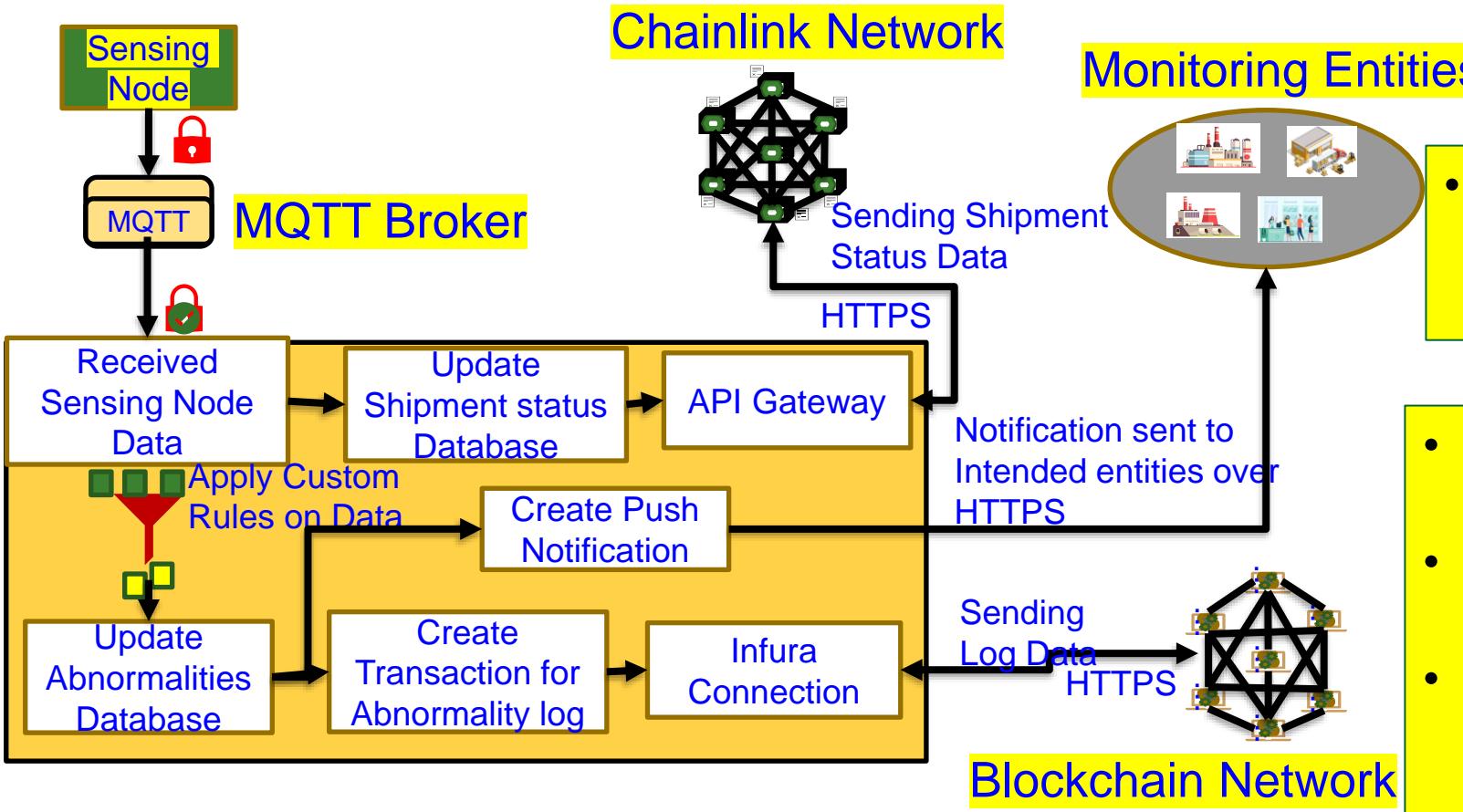
PharmaChain Sensing Node



- 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

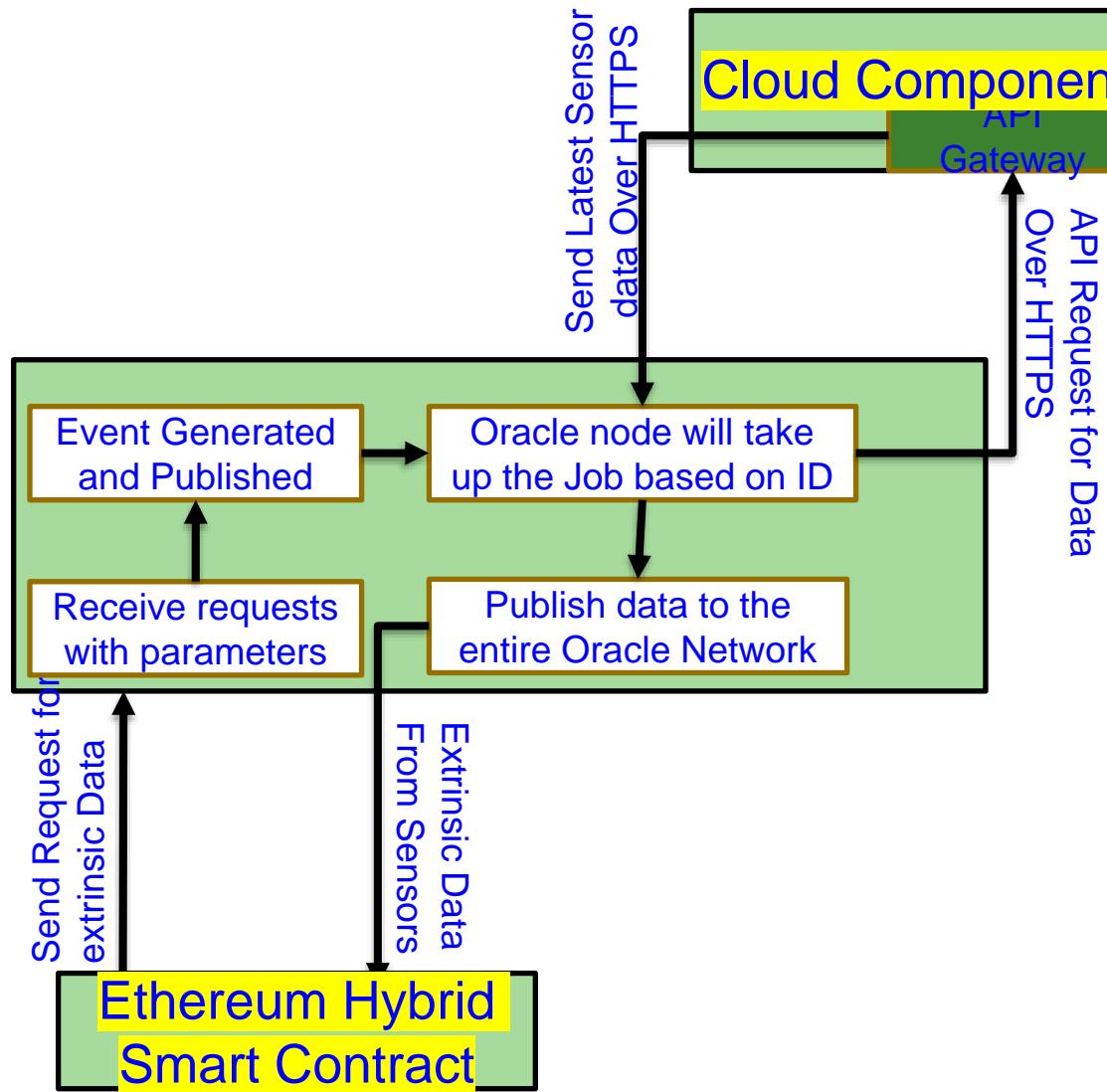


- Smart contracts cannot interact with API or external environmental data

- 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>

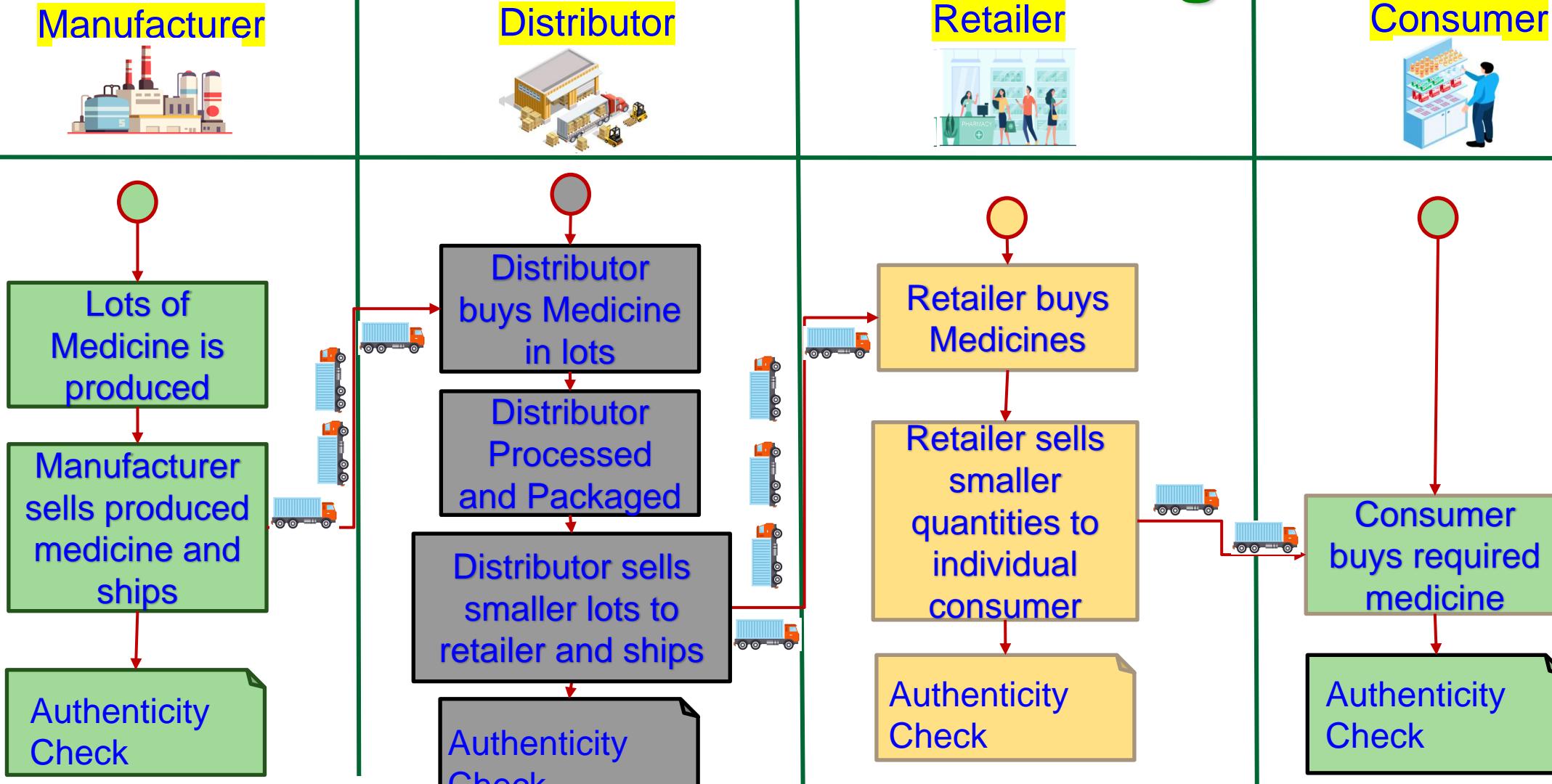
PharmaChain Oracle Component



- 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>

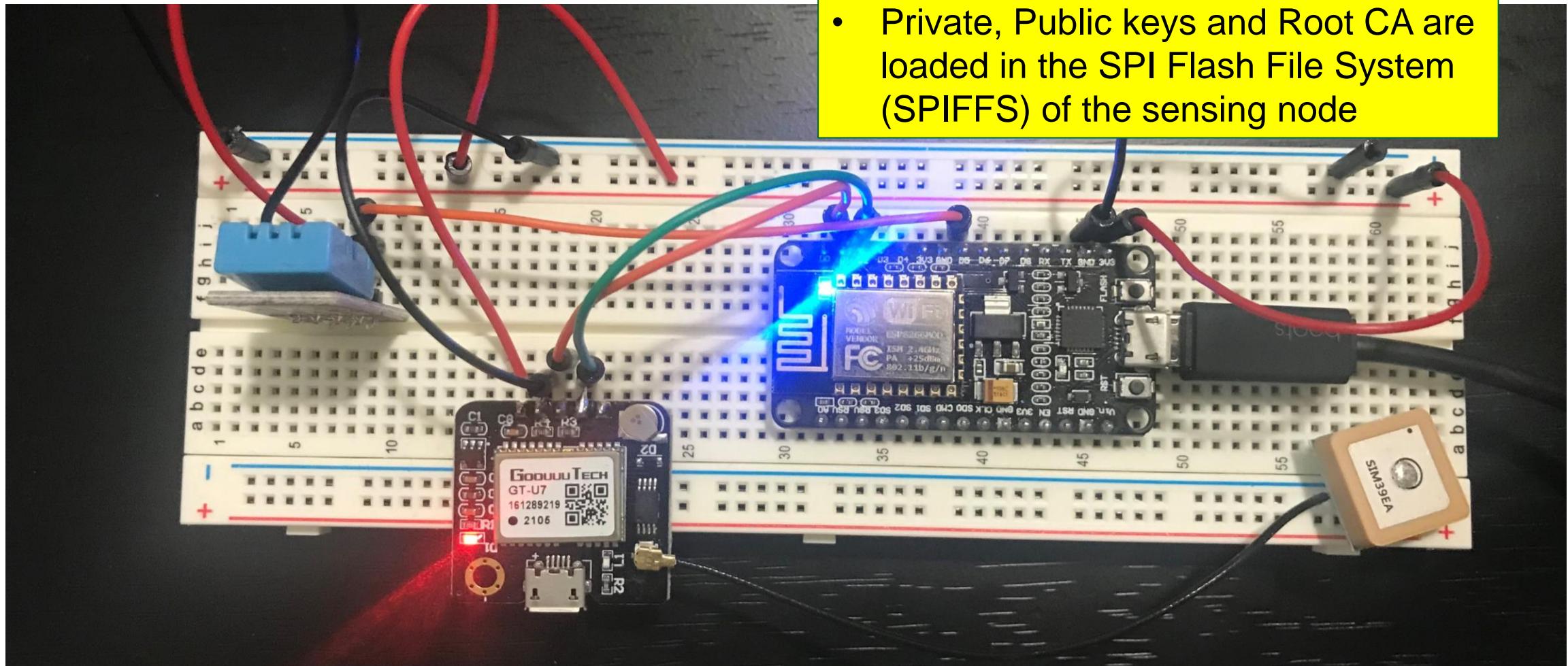
PharmaChain Entity Diagram



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

```
COM3
....scandone
state: 0 -> 2 (b0)
.state: 2 -> 3 (0)
state: 3 -> 5 (10)
add 0
aid 1
cnt

connected with LifeEhOkaZindagi, channel 11
dhcp client start...
ip:192.168.1.62,mask:255.255.255.0,gw:192.168.1.1
.
WiFi connected
IP address:
192.168.1.62
Heap: 32632
Successfully opened cert file
cert loaded
Successfully opened private cert file
private key loaded
Successfully opened open ca
ca loaded
Heap: 29016
Attempting MQTT connection...pm open,type:2 0
connected
Publish message: {"timestamp": " ", "latitude": 0, "longitude": 0, "sku": 2112101, "lot": 547863250, "drugname": "Mucinex", "temperature": 21.5, "humidity": 60}
Heap: 23584
Publish message: {"timestamp": " ", "latitude": 0, "longitude": 0, "sku": 2112101, "lot": 547863250, "drugname": "Mucinex", "temperature": 21.5, "humidity": 60}
Heap: 23696
Publish message: {"timestamp": "11 / 01 / 2022 04 : 27 : 01 AM ", "latitude": 33.21301, "longitude": -97.15771, "sku": 2112101, "lot": 547863250, "drugname": "Mucinex", "temperature": 21.5, "humidity": 61}
Heap: 23592
Publish message: {"timestamp": "11 / 01 / 2022 04 : 27 : 18 AM ", "latitude": 33.213, "longitude": -97.15753, "sku": 2112101, "lot": 547863250, "drugname": "Mucinex", "temperature": 21.5, "humidity": 61}
Heap: 23592
Publish message: {"timestamp": "11 / 01 / 2022 04 : 27 : 28 AM ", "latitude": 33.21297, "longitude": -97.1575, "sku": 2112101, "lot": 547863250, "drugname": "Mucinex", "temperature": 21.5, "humidity": 61}
Heap: 23592
Publish message: {"timestamp": "11 / 01 / 2022 04 : 27 : 33 AM ", "latitude": 33.21295, "longitude": -97.15753, "sku": 2112101, "lot": 547863250, "drugname": "Mucinex", "temperature": 21.4, "humidity": 61}
Heap: 23592
Publish message: {"timestamp": "11 / 01 / 2022 04 : 27 : 40 AM ", "latitude": 33.21297, "longitude": -97.15757, "sku": 2112101, "lot": 547863250, "drugname": "Mucinex", "temperature": 21.4, "humidity": 61}
Heap: 23592
Publish message: {"timestamp": "11 / 01 / 2022 04 : 27 : 49 AM ", "latitude": 33.21296, "longitude": -97.15765, "sku": 2112101, "lot": 547863250, "drugname": "Mucinex", "temperature": 21.4, "humidity": 61}
Heap: 23592
Publish message: {"timestamp": "11 / 01 / 2022 04 : 28 : 02 AM ", "latitude": 33.21296, "longitude": -97.15772, "sku": 2112101, "lot": 547863250, "drugname": "Mucinex", "temperature": 21.4, "humidity": 61}
Heap: 23592
Publish message: {"timestamp": "11 / 01 / 2022 04 : 28 : 02 AM ", "latitude": 33.21296, "longitude": -97.15772, "sku": 2112101, "lot": 547863250, "drugname": "Mucinex", "temperature": 21.4, "humidity": 61}
Heap: 23592
Publish message: {"timestamp": "11 / 01 / 2022 04 : 28 : 28 AM ", "latitude": 33.21297, "longitude": -97.1575, "sku": 2112101, "lot": 547863250, "drugname": "Mucinex", "temperature": 21.4, "humidity": 61}
Heap: 23592
Publish message: {"timestamp": "11 / 01 / 2022 04 : 28 : 35 AM ", "latitude": 33.21297, "longitude": -97.15747, "sku": 2112101, "lot": 547863250, "drugname": "Mucinex", "temperature": 21.4, "humidity": 61}
Heap: 23592
Publish message: {"timestamp": "11 / 01 / 2022 04 : 28 : 42 AM ", "latitude": 33.21297, "longitude": -97.15752, "sku": 2112101, "lot": 547863250, "drugname": "Mucinex", "temperature": 21.4, "humidity": 61}

Newline
Autoscroll
Show timestamp
115200 baud
Clear output
```

Loading all necessary RSA Key and Certificate files and establishing secure connection before publishing data

Published data from 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>

Implemented Cloud Component

RULE APIUpdate

The source of the messages you want to process with this rule.

```
SELECT * FROM `esp32/pub`
```

Using SQL version 2016-03-23

Actions

Actions are what happens when a rule is triggered. [Learn more](#)

- Send a message to a Lambda function updatedB

Environment

Go to Anything (Ctrl-P)

AddPharmaChainTemperatureAbnormalDB / index.js

```
index.js
1 const AWS = require("aws-sdk");
2
3 const dynamo = new AWS.DynamoDB.DocumentClient();
4
5 exports.handler = function (event, context,callback) {
6     console.log(event);
7     var params={
8         Item:{
9             timestamp: event['timestamp'],
10            latitude: event['latitude'],
11            longitude: event['longitude'],
12            sku : event['sku'],
13            lot : event['lot'],
14            drugname : event['drugname'],
15            temperature : event['temperature'],
16            humidity : event['humidity']
17        },
18
19    };
20
21    TableName : 'TemperatureAbnormalNotification'
22    );
23    dynamo.put(params, function(err,data){
24        if(err){
25            callback(err,null);
26        }
27        else{
28            callback(null,null);
29        }
30    });
31}
```

- Adding abnormal temperatures to DB

RULE PharmaChainNode_IoTRule

ENABLED

The source of the messages you want to process with this rule.

```
SELECT * FROM `esp32/pub` where temperature > 25
```

Using SQL version 2016-03-23

Actions

Actions are what happens when a rule is triggered. [Learn more](#)

- Send a message as an SNS push notification snsnodemcu
- Send a message to a Lambda function AddPharmaChainTemperatureAbnormalDB

Environment

Go to Anything (Ctrl-P)

lambdaFunctionForAPI / index.js

```
index.js
1 const AWS = require("aws-sdk");
2
3 const dynamo = new AWS.DynamoDB.DocumentClient();
4
5 exports.handler = async (event, context) => {
6     let body;
7     let statusCode = 200;
8     const headers = {
9         "Content-Type": "application/json"
10    };
11
12    try{
13        switch (event.routeKey) {
14            case "GET/item/{sku}":
15                let params = {
16                    // Specify which items in the results are returned.
17                    FilterExpression: "sku = :sku",
18                    // Define the expression attribute value, which are substitutes for the values you want to compare.
19                    ExpressionAttributeValues: {
20                        ":sku": parseInt(event.pathParameters.sku),
21                    },
22                    // Set the projection expression, which are the attributes that you want.
23                    //ProjectionExpression: "",
24                    TableName: "PharmacainSKULatestDB",
25                };
26                body = await dynamo.scan(params).promise();
27                console.log(event.pathParameters.sku)
28                console.log(params.ExpressionAttributeValues)
29                break;
30            default:
31                throw new Error(`Unsupported route: "${event.routeKey}"`);
32        }
33    } catch (err) {
34        statusCode = 400;
35        body = err.message;
36    } finally {
37    }
38}
```

- 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

snsnodemcu <no-reply@sns.amazonaws.com>
to me ▾

{"timestamp": "29 / 12 / 2021 07 : 11 : 53 AM ", "latitude": "33.212971", "longitude": "-97.157799", "sku": "PF02112101", "lot": 547863250, "drugname": "pfizer Vaccine", "temperature": 24.9, "humidity": 40}
--
If you wish to stop receiving notifications from this topic, please click or visit the link below to unsubscribe:
<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>
Please do not reply directly to this email. If you have any questions or comments regarding this email, please contact us at <https://aws.amazon.com/support>

snsnodemcu <no-reply@sns.amazonaws.com>
to me ▾

{"timestamp": "29 / 12 / 2021 07 : 11 : 54 AM ", "latitude": "33.212971", "longitude": "-97.157799", "sku": "PF02112101", "lot": 547863250, "drugname": "pfizer Vaccine", "temperature": 24.9, "humidity": 40}

snsnodemcu <no-reply@sns.amazonaws.com>
to me ▾

{"timestamp": "29 / 12 / 2021 07 : 11 : 55 AM ", "latitude": "33.212971", "longitude": "-97.157799", "sku": "PF02112101", "lot": 547863250, "drugname": "pfizer Vaccine", "temperature": 24.9, "humidity": 40}

snsnodemcu <no-reply@sns.amazonaws.com>
to me ▾

{"timestamp": "29 / 12 / 2021 07 : 11 : 56 AM ", "latitude": "33.212971", "longitude": "-97.157799", "sku": "PF02112101", "lot": 547863250, "drugname": "pfizer Vaccine", "temperature": 24.9, "humidity": 40}

snsnodemcu <no-reply@sns.amazonaws.com>
to me ▾

{"timestamp": "29 / 12 / 2021 07 : 11 : 57 AM ", "latitude": "33.212971", "longitude": "-97.157799", "sku": "PF02112101", "lot": 547863250, "drugname": "pfizer Vaccine", "temperature": 24.9, "humidity": 40}

snsnodemcu <no-reply@sns.amazonaws.com>
to me ▾

{"lot": 547863250, "timestamp": "29 / 12 / 2021 07 : 14 : 59 AM ", "longitude": "-97.157799", "humidity": 40, "drugname": "pfizer Vaccine", "latitude": "33.212971", "temperature": 26, "sku": "PF02112101"}

 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>

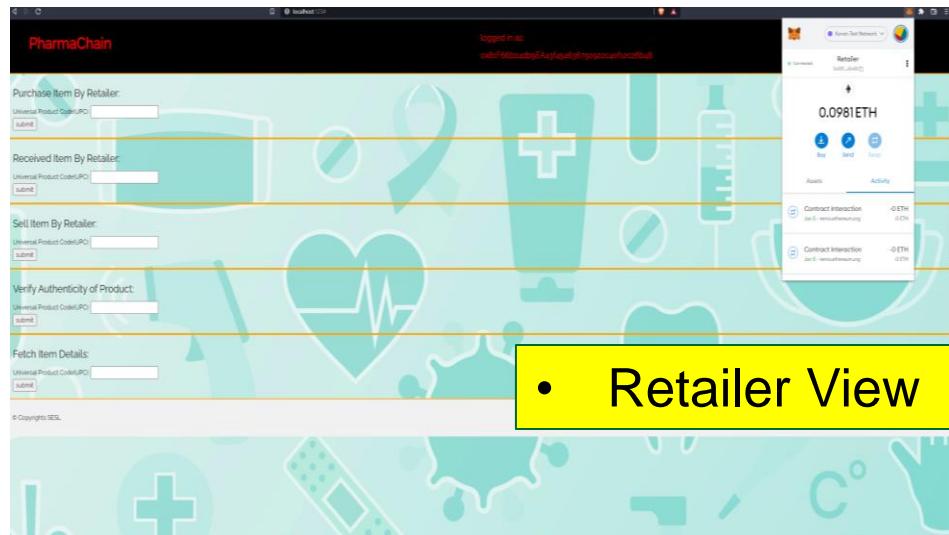
Web DApp Interface



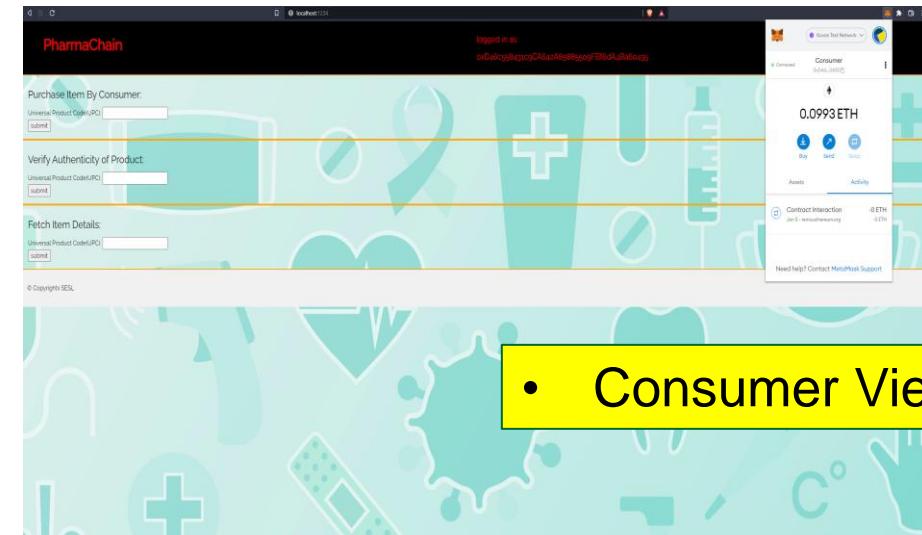
• Manufacturer View



• 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

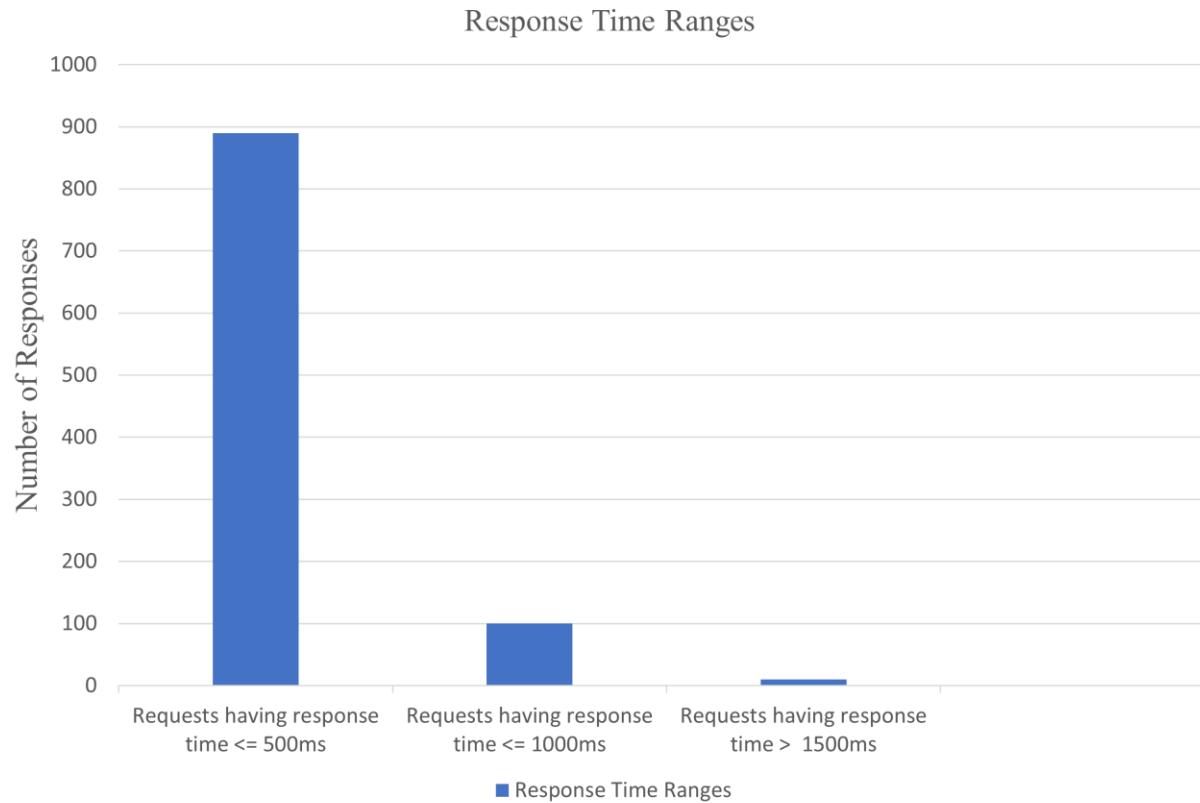
The screenshot displays the PharmaChain web application interface. At the top, there is a black header bar with the text "PharmaChain" on the left and "logged in as: 0xD46c558431c9CA642A85885509FBf6dA4Ba60435" on the right. Below the header, there are three main sections:

- Purchase Item By Consumer:** A form with a placeholder "Universal Product Code(UPC)" and a "submit" button.
- Verify Authenticity of Product:** A form with a placeholder "Universal Product Code(UPC)" and a "submit" button. Below the form, it shows "UPC: 547863250" and "SKU: 2112101". It also displays a series of verified transfer steps:
 - Verified transfer from manufacturer to distributor at block number: 29223086
 - Verified transfer from distributor to retailer at block number: 29223296
 - Verified transfer from retailer to consumer at block number: 29223390A message "Product is verified ✓" is shown below these transfers.
- Fetch Item Details:** A form with a placeholder "Universal Product Code(UPC)" and a "submit" button.

At the bottom of the page, there is a copyright notice: "© Copyrights SESL".

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>

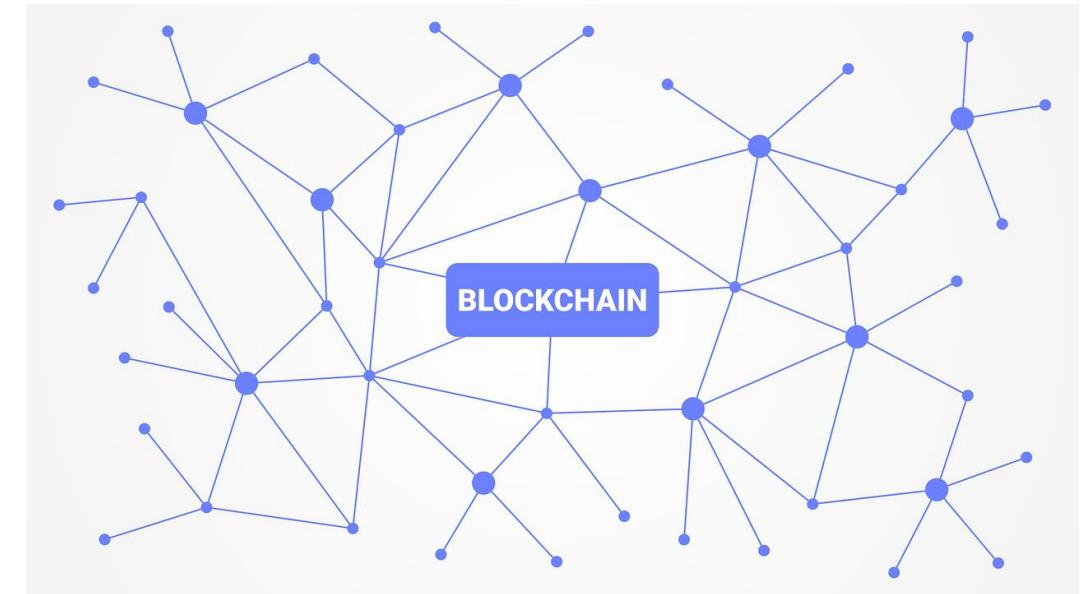
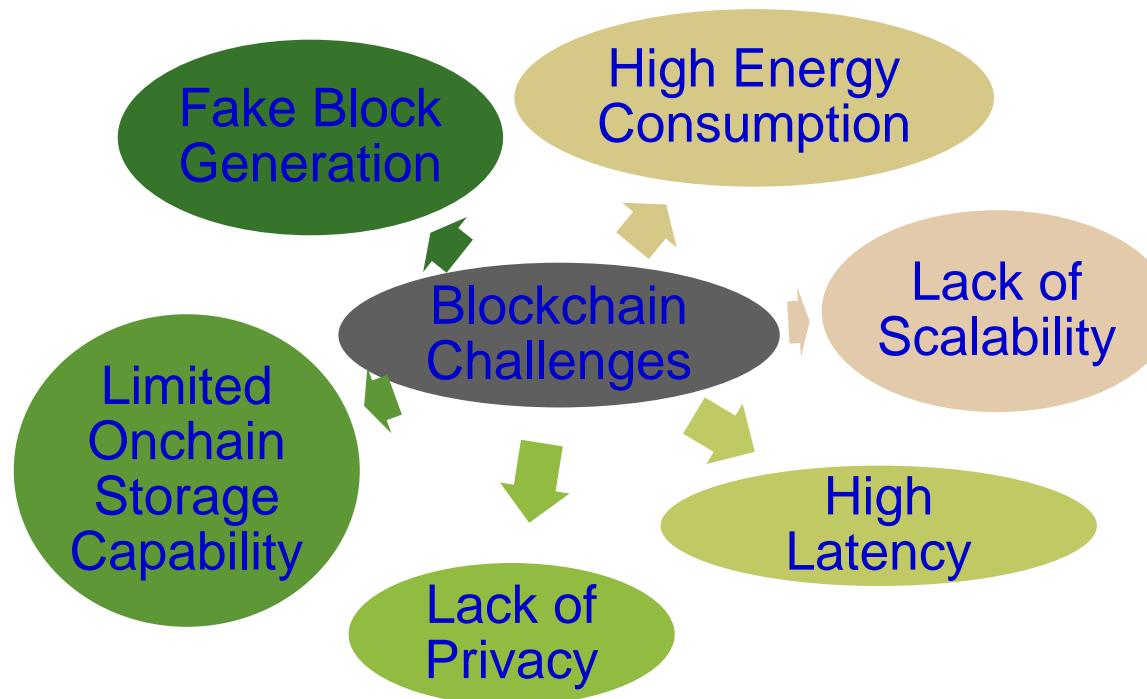
Performance and Cost Analysis



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

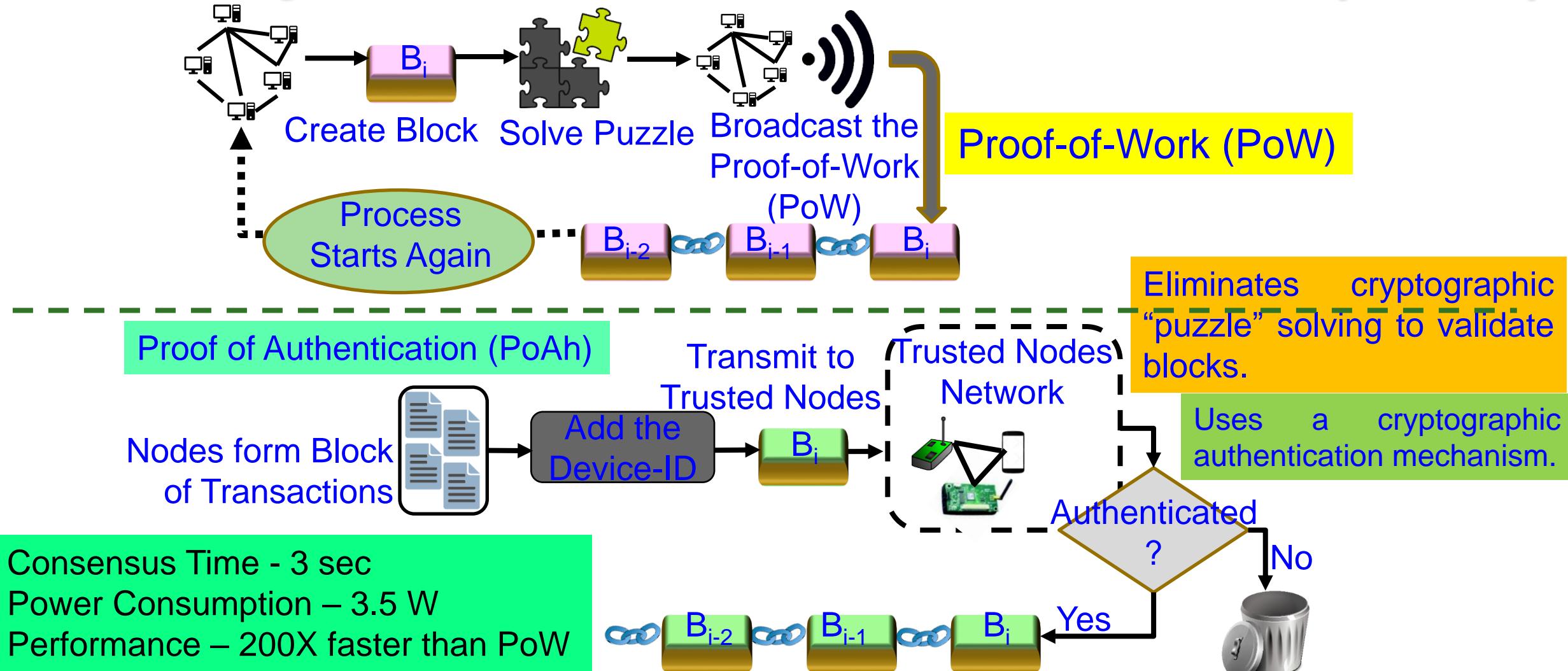
Source: Bapatla, A.K., et al.: PharmaChain: a blockchain to ensure counterfeit-free pharmaceutical supply chain. IET Netw. 1– 24 (2022). <https://doi.org/10.1049/ntw2.12041>

Blockchain has Many Challenges



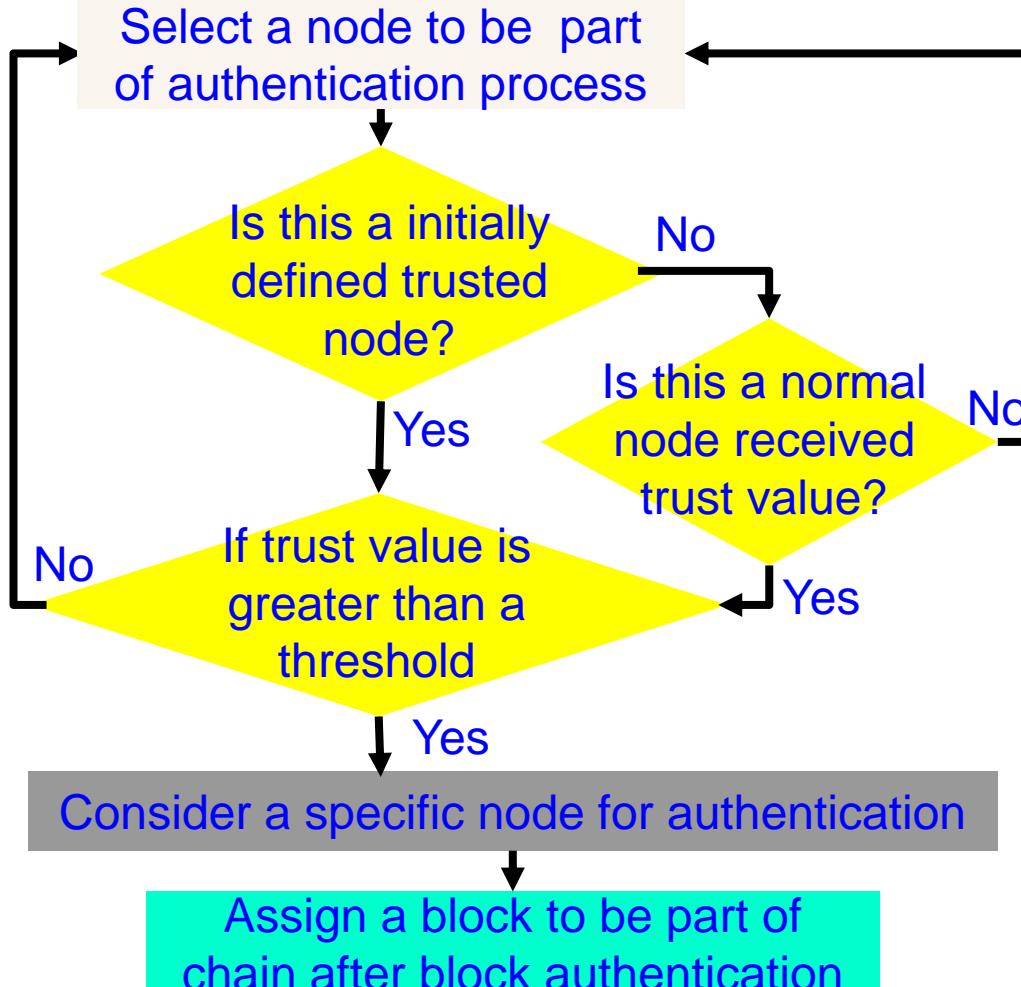
Source: D. Puthal, N. Malik, S. P. Mohanty, E. Kougianos, and G. Das, "Everything you Wanted to Know about the Blockchain", *IEEE Consumer Electronics Magazine (CEM)*, Volume 7, Issue 4, July 2018, pp. 06--14.

Our EasyChain: Proof-of-Authentication (PoAh)



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
 $(Trx^+) \rightarrow \text{blocks}$
- (2) Blocks sign with own private key
 $S_{PrK}(\text{block}) \rightarrow \text{broadcast}$
- (3) Trusted node verifies signature with source public key
 $V_{PuK}(\text{block}) \rightarrow \text{MAC Checking}$
- (4) If (Authenticated)
 $\text{Block} || \text{PoAh}(\text{ID}) \rightarrow \text{broadcast}$
 $H(\text{block}) \rightarrow \text{Add blocks into chain}$
- (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



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>

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 today.

11/12/2021

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

08/24/2021

ALEXANDRIA, 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.

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.

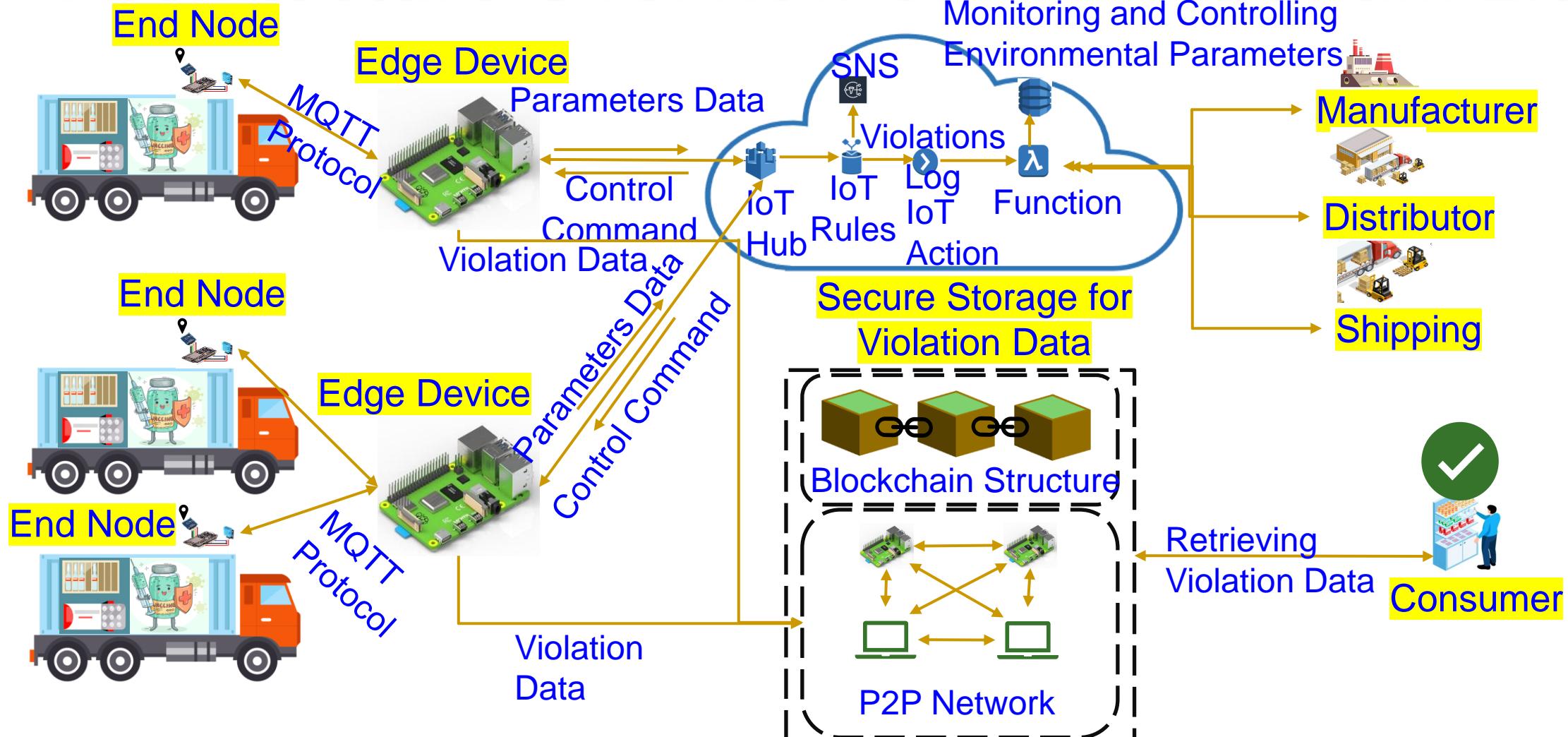
Novel Contributions

- 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

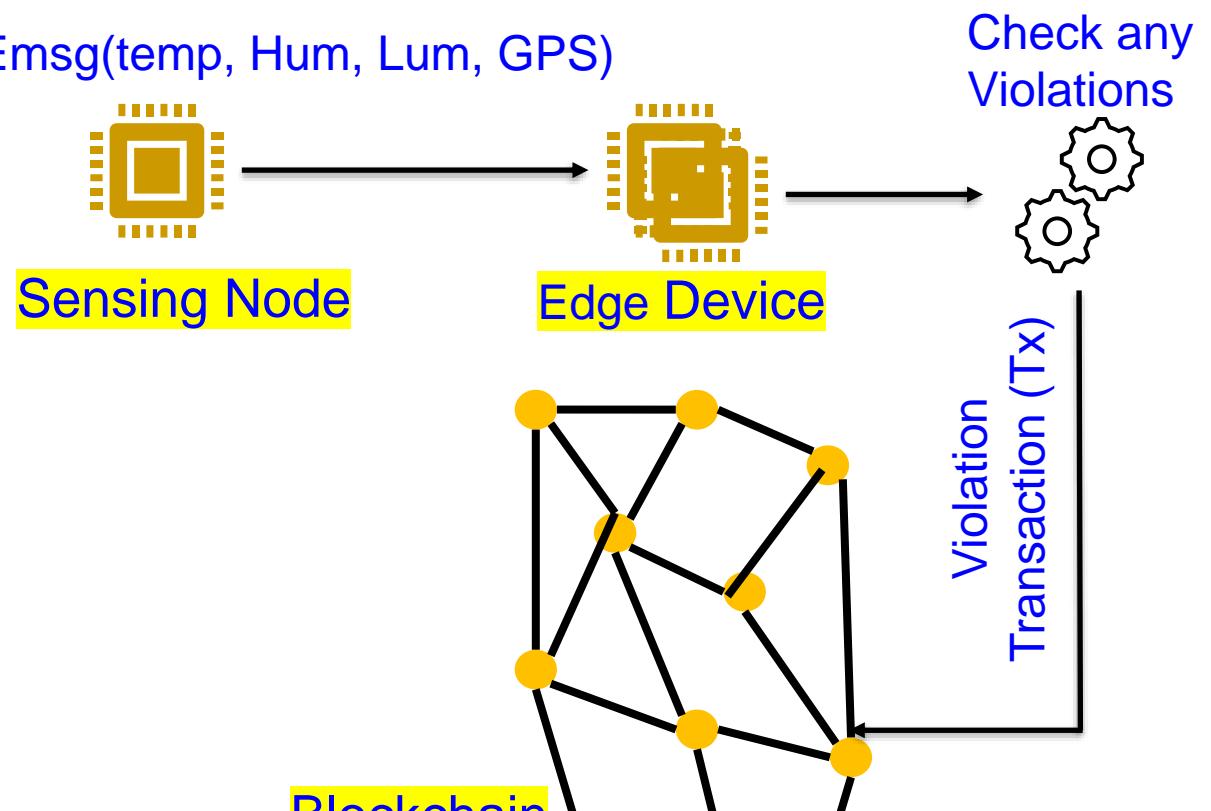
Output: Violation data transaction published to blockchain network and cloud layer

- 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: $E_e.PUBLISH(\tau, E_{msg}(\text{temp}, \text{Hum}, \text{lum}, \text{GPS}))$
- 4: Edge device E_e consumes the messages sent by the end nodes
- 5: $E_e.consume(\tau)$

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:       $Tx \leftarrow E_e.prepareTransaction(V_E)$ 
14:       $E_e.generateTransaction(Tx)$ 
15:    end if
16:   end for
17: end procedure
```

$Emsg(\text{temp}, \text{Hum}, \text{lum}, \text{GPS})$



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.

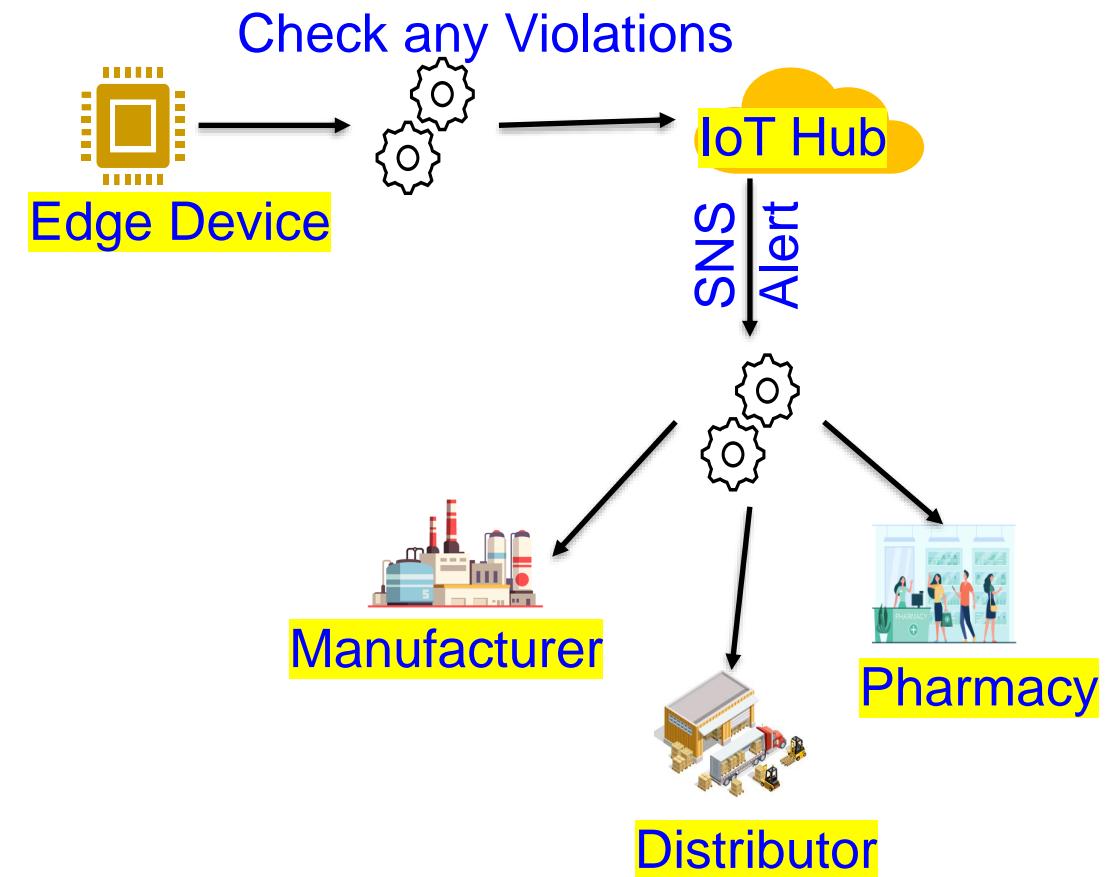
Proposed Algorithm – Log Generation

Phase 2 – Cloud Layer Processing

```
18: procedure CLOUD LAYER PROCESSING
19:   for Every Violation Data  $V_E$  received do
20:     Consume the message
21:     IoTHub.consume( $V_E$ )
22:     Generate an alert using SNS (Simple Notification Service) to the registered entities
23:     SNS.generateAlert( $V_E$ )
24:   end for
25: end procedure
```

Phase 3 – Blockchain Layer Processing

```
26: procedure BLOCKCHAIN LAYER PROCESSING
27:   Generated transaction is received into unconfirmed transactions pool (UTx)
28:   UTx.append(Tx)
29:   Miner picks transaction from UTx pool and creates a block
30:   Mining performed based on PoAh consensus protocol
31:   New block is added to the chain at all the participating nodes in the network creating an immutable violation data log
32:
33: end procedure
```

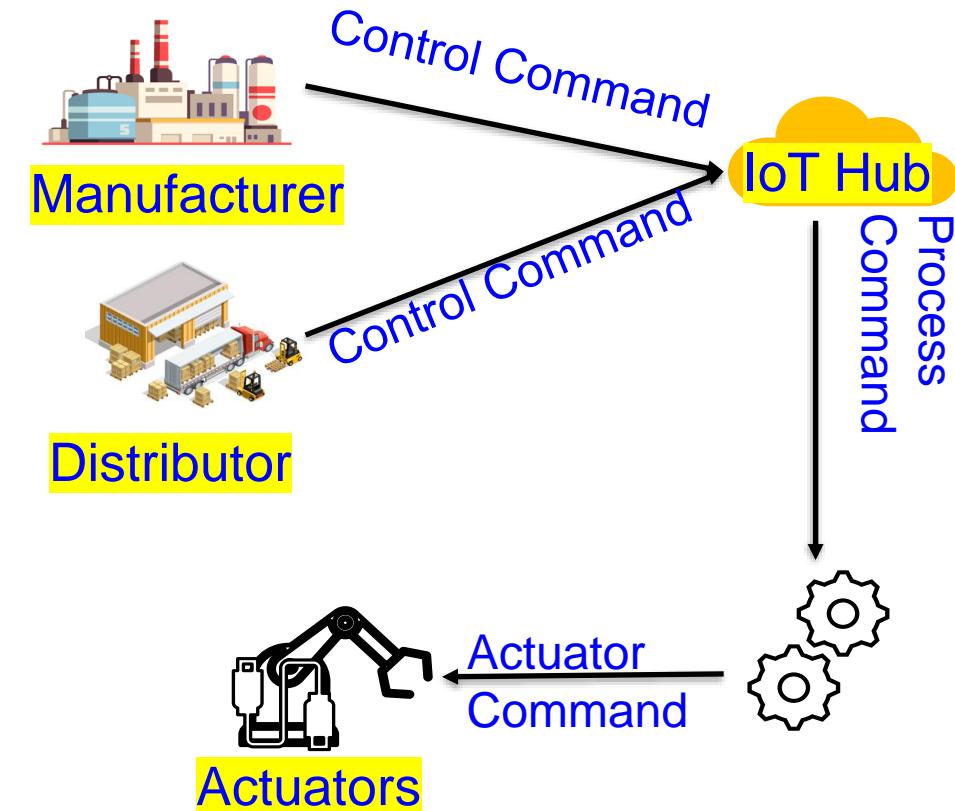


Source: A. K. Bapatla, **S. P. Mohanty**, E. Koulianou, and D. Puthal, "PharmaChain 2.0: A Blockchain Framework for Secure Remote Monitoring of Drug Environmental Parameters in Pharmaceutical Cold Supply Chain", in *Proceedings of the IEEE International Symposium on Smart Electronic Systems (iSES)*,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

Proposed Algorithm- Control Algorithm

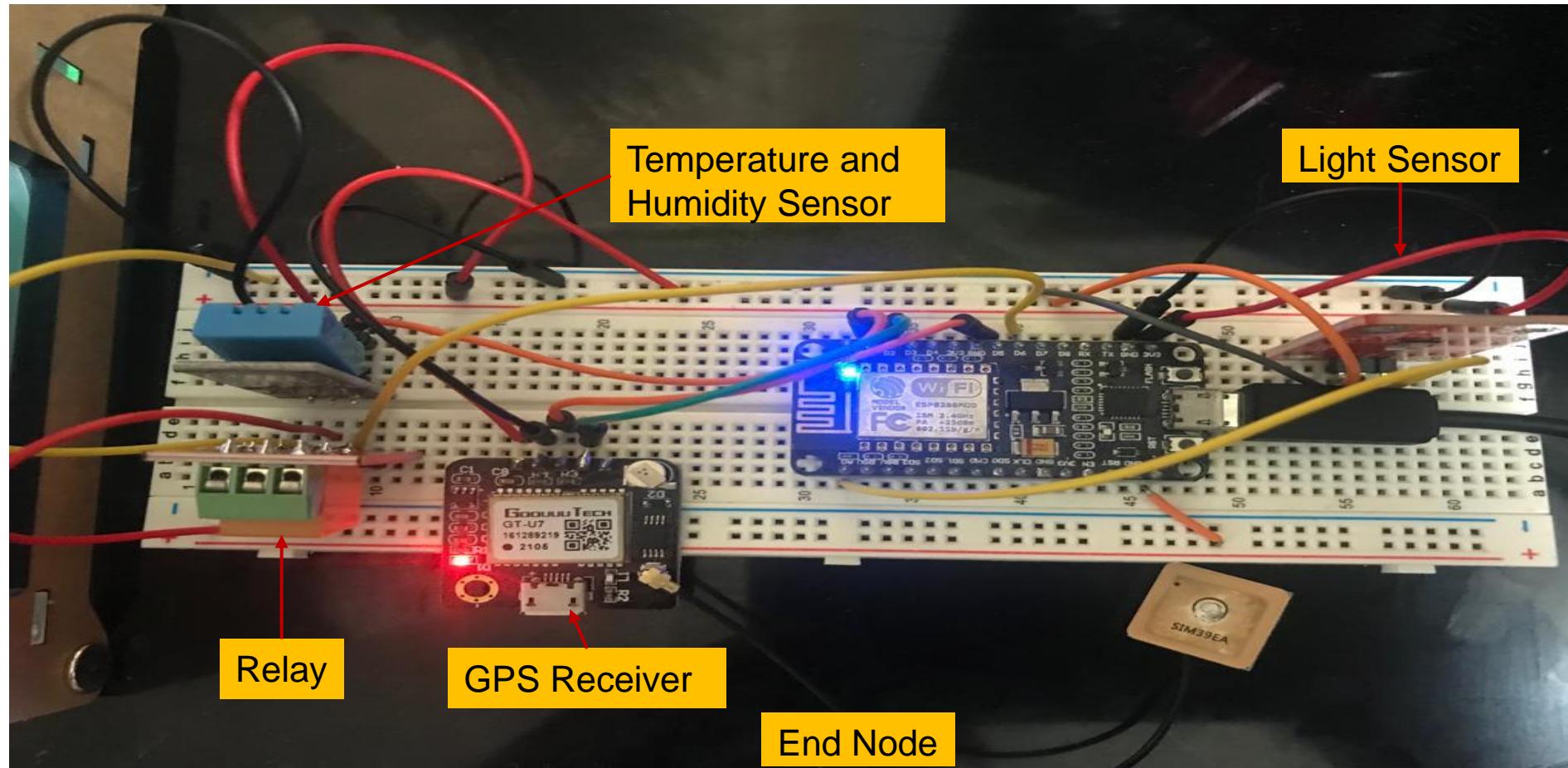
Algorithm 2 Proposed Control Algorithm For PharmaChain 2.0

```
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

```
pi@raspberrypi2:~/Desktop/Implementation_python
pi login as: pi
pi's password:
Linux raspberrypi2 5.10.92-v7l+ #1514 SMP Mon Jan 17 17:38:03 GMT 2022 armv7l

The programs included with the Debian GNU/Linux system are free software;
the exact distribution terms for each program are described in the
individual files in /usr/share/doc/*copyright.

Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the extent
permitted by applicable law.
Last login: Tue Feb 1 19:03:56 2022
pi@raspberrypi2:~ $ cd Desktop/Impl*
pi@raspberrypi2:~/Desktop/Implementation_python $ python3 app.py 1234 1
 * Serving Flask app 'app' (lazy loading)
 * Environment: production
   WARNING: This is a development server. Do not use it in a production deployment.
   Use a production WSGI server instead.
 * Debug mode: off
 * Running on all addresses.
   WARNING: This is a development server. Do not use it in a production deployment
nt.
 * Running on http://[REDACTED]:1234/ (Press CTRL+C to quit)
```

(a) Edge Device Running Proof of Authentication Based Blockchain



(e) Implemented Four Node Prototype for PharmaChain 2.0

```
pi@raspberrypi2:~/Desktop/Implementation_python
pi login as: pi
pi's password:
Linux raspberrypi2 5.10.92-v7l+ #1514 SMP Mon Jan 17 17:38:03 GMT 2022 armv7l

The programs included with the Debian GNU/Linux system are free software;
the exact distribution terms for each program are described in the
individual files in /usr/share/doc/*copyright.

Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the extent
permitted by applicable law.
Last login: Tue Feb 1 22:42:31 2022
pi@raspberrypi2:~ $ cd Desktop/Implementation_python
pi@raspberrypi2:~/Desktop/Implementation_python $ python3 app.py 3456 3
 * Serving Flask app 'app' (lazy loading)
 * Environment: production
   WARNING: This is a development server. Do not use it in a production deployment.
   Use a production WSGI server instead.
 * Debug mode: off
 * Running on all addresses.
   WARNING: This is a development server. Do not use it in a production deployment
nt.
 * Running on http://[REDACTED]:3456/ (Press CTRL+C to quit)
```

(b) Edge Device Running Proof of Authentication Based Blockchain

```
pi@raspberrypi3:~/Desktop/Implementation_python
pi login as: pi
pi's password:
Linux raspberrypi3 5.10.63-v7l+ #1459 SMP Wed Oct 6 16:41:57 BST 2021 armv7l

The programs included with the Debian GNU/Linux system are free software;
the exact distribution terms for each program are described in the
individual files in /usr/share/doc/*copyright.

Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the extent
permitted by applicable law.
Last login: Tue Feb 1 22:42:32 2022
pi@raspberrypi3:~ $ cd Desktop/Impl*
pi@raspberrypi3:~/Desktop/Implementation_python $ python3 app.py 4567 4
 * Serving Flask app 'app' (lazy loading)
 * Environment: production
   WARNING: This is a development server. Do not use it in a production deployment.
   Use a production WSGI server instead.
 * Debug mode: off
 * Running on all addresses.
   WARNING: This is a development server. Do not use it in a production deployment.
 * Running on http://[REDACTED]:4567/ (Press CTRL+C to quit)
```

(d) Edge Device Running Proof of Authentication Based Blockchain

```
pi@raspberrypi1:~/Desktop/Implementation_python
pi login as: pi
pi's password:
Linux raspberrypi1 5.10.17-v7l+ #1403 SMP Mon Feb 22 11:33:35 GMT 2021 armv7l

The programs included with the Debian GNU/Linux system are free software;
the exact distribution terms for each program are described in the
individual files in /usr/share/doc/*copyright.

Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the extent
permitted by applicable law.
Last login: Tue Feb 1 22:31:44 2022 from 192.168.1.235
pi@raspberrypi1:~ $ cd Desktop/Implementation_python
pi@raspberrypi1:~/Desktop/Implementation_python $ python3 app.py 2345 2
 * Serving Flask app 'app' (lazy loading)
 * Environment: production
   WARNING: This is a development server. Do not use it in a production deployment
nt.
 * Use a production WSGI server instead.
 * Debug mode: off
 * Running on all addresses.
   WARNING: This is a development server. Do not use it in a production deployment
nt.
 * Running on http://[REDACTED]:2345/ (Press CTRL+C to quit)
```

(c) 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

The screenshot shows a POST request to `http://[REDACTED]:1234/blockchain`. The response body is a JSON object representing a blockchain chain. The chain consists of two blocks. The first block has index 1, timestamp 1659294689, and hash 0. It contains no transactions. The second block has index 2, timestamp 1659295888, and hash a96d8768a9ac402651854228a09681cbe7f5dc8edb703645818090827e4e6a75. This block contains a single transaction with sourceid 2, destinationid 3, macid dca6327e10af, and data about a COVID-19 vaccine shipment. The transaction data includes fields like Vaccine Name, Manufacturer, Manufactured Date, Batch Number, Shipment ID, Type of Violation (Temperature), and Violation Value (23). A red bracket labeled "Violation Data in Distributed Ledger" groups this transaction data. Below the transaction, a red bracket labeled "Encoded Encrypted Transaction Data" groups the entire JSON structure of the second block. Another red bracket labeled "Encoded Digital Signature" groups the "pending_transactions" field, which contains the encoded digital signature for the second block.

```
GET https://[REDACTED]:1234/blockchain
Status: 200 OK Time: 50 ms Size: 2.88 KB Save Response

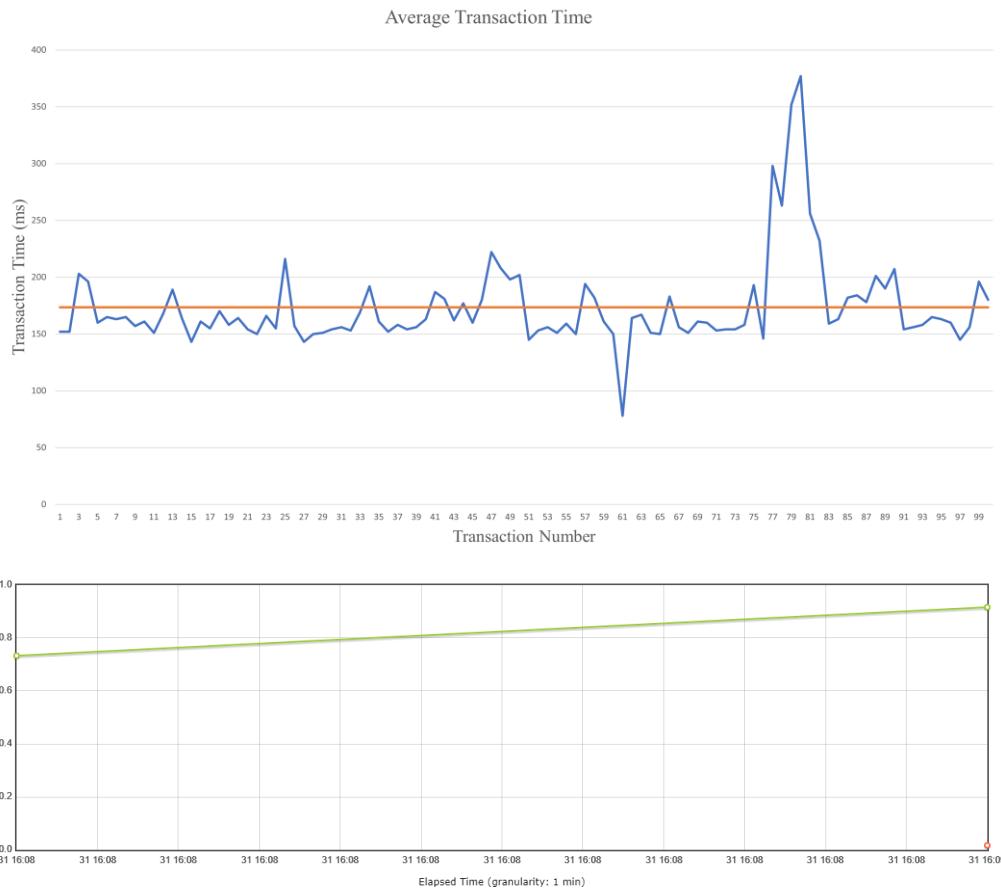
Params Authorization Headers (6) Body Pre-request Script Tests Settings
Body Cookies Headers (5) Test Results
Pretty Raw Preview Visualize JSON ↻

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{
  "chain": [
    {
      "index": 1,
      "timestamp": 1649398628,
      "transactions": [],
      "poash": "0",
      "hash": "0",
      "previous_block_hash": "0"
    },
    {
      "index": 2,
      "timestamp": 1659294689,
      "transactions": [
        {
          "sourceid": "2",
          "destinationid": "3",
          "macid": "dca6327e10af",
          "data": {
            "Vaccine Name": "COVID-19",
            "Vaccine Manufacturer": "Pfizer",
            "Manufactured Date": "06312022",
            "Batch Number": "PFCV001",
            "Shipment ID": "00001",
            "Type of Violation": "Temperature",
            "Violation Value": "23"
          },
          "digitalsign": "C0CY2ucLtu1qm(cN," + poash
        }
      ],
      "poash": 60733,
      "hash": "a96d8768a9ac402651854228a09681cbe7f5dc8edb703645818090827e4e6a75",
      "previous_block_hash": "0"
    }
  ],
  "pending_transactions": [],
  "network_nodes": [
    "http://[REDACTED]:3456",
    "http://[REDACTED]:3456",
    "http://[REDACTED]:4567"
  ],
  "current_node_url": "http://[REDACTED]:1234",
  "current_node_macid": "dca6327e0f66",
  "current_node_sourceid": "1",
  "d": {
    "1": [
      "dca6327e0f66",
      "http://[REDACTED]:1234"
    ],
    "2": [
      "dca6327e10af",
      "http://[REDACTED]:2345"
    ],
    "3": [
      "dca6327e0f66",
      "http://[REDACTED]:3456"
    ],
    "4": [
      "dca6327e0f64",
      "http://[REDACTED]:4567"
    ]
  }
}

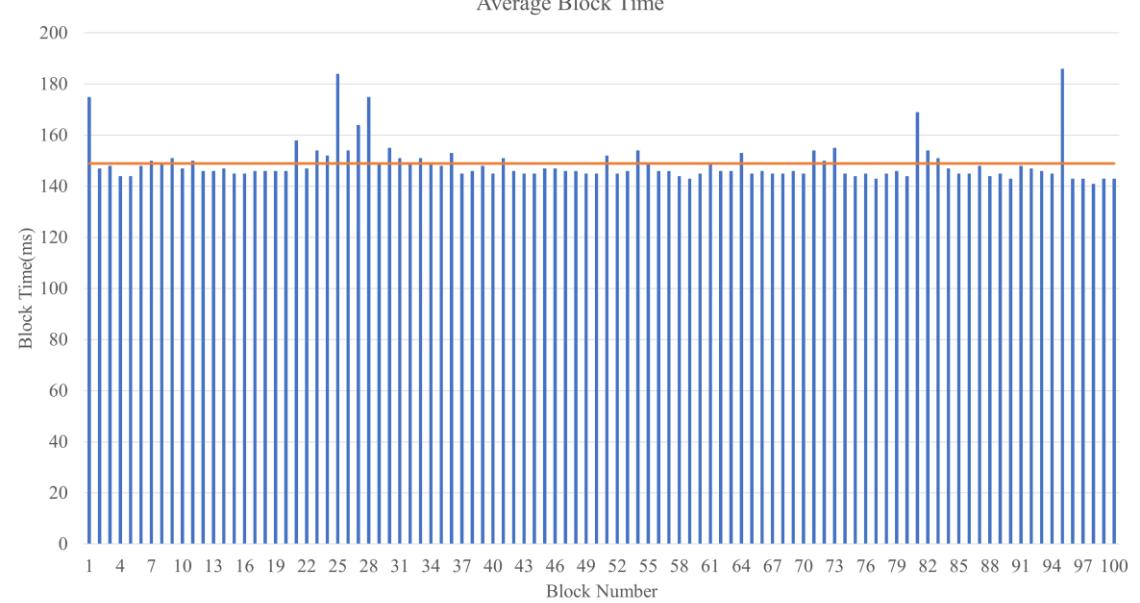
```

Testbed Evaluation



	Transaction Time	Block Time	Total Time
PharmaChain 2.0	173.39ms	148.89 ms	322.2 8ms

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

Conclusion

- This paper presents a **novel lightweight blockchain solution** to ensure the safe handling of medicines carried in the cold supply chain.
- The proposed PharmaChain 2.0 provides **continuous monitoring and control capabilities** for different entities in the Pharmaceutical Supply Chain to take prompt actions for shipments.
- PharmaChain 2.0 works based on the lightweight consensus mechanism Proof-of-Authentication (PoAh) which is **cost-efficient as no mining fees** are involved and not computationally intensive, unlike other established consensus protocols.

Analysis Summary of PharmaChain 2.0

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

Future Research

- In future work, we try to include more complex interaction scenarios between multiple entities in the pharmaceutical supply chains.
- User-friendly UI design can help to navigate through different functions provided by PharmaChain 2.0.
- Increasing the efficiency and throughput of the proposed system by further improving the consensus mechanism.
- Automating the procedures within the pharmaceutical supply chain to reduce latencies.

Thank You !!