FogChain: A Fog computing architecture integrating Blockchain and Internet of Things for Personal Health Records

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Summary

➢ Introduction
➢ Background
➢ Related Work
➢ **FogChain** Architecture Model
➢ Methodology
➢ Conclusion
➢ Publications
➢ Schedule
Introduction - Research Problem

❖ Patient’s health records:
  – Possibly **scattered** and **fragmented** among multiple organizations (hospitals and clinics);
  – Records are **not** up-to-date, shared;
  – Patients repeating exams due to lack of interoperability;
Introduction - Research Problem

❖ How to improve **patients outcomes** regarding health data?
❖ How to **secure** and facilitate patients access and management to their own **personal** health records (PHR)?

➢ To propose and design an **architectural model** capable of **improving** patient’s experience and **outcomes** based on collected health data (IoHT) to be safely stored in a **Blockchain** with **fog computing** support.
Introduction - Motivation

➢ Recent researches predict that centralized clouds, which are frequently used in current IoT systems, will be unlikely to deliver satisfactory services to customers in the near future (SHARMA; CHEN; PARK, 2018).

➢ The process of collecting vital signs in hospital wards varies, and different approaches are used worldwide. In some cases, data is only manually collected, and stored in spreadsheets that are discarded after the patient is discharged (COSTA et al., 2018).
• A more patient-centric healthcare solution:
  – Rethink current standards and propose solutions for the benefit of patients.

• Seek alternatives and innovative solutions for healthcare domain.
Introduction - Research Question

❖ How could be described a model for the integration of Blockchain and Internet of Things technologies for Personal Health Records (PHR) using Fog Computing?
Introduction - Scientific contribution

✓ **Taxonomy** classification into the state of the art;
✓ **Model** supporting PHR management with fog computing design integrating IoHT and Blockchain;
✓ **Prototype** implementation of a Blockchain with smart contracts support;
✓ **Benchmark** evaluation and analysis;
✓ **Steps for automation** of vital signs collecting process.
Background – EHR vs PHR

**EHR**
- Health providers *control*

**PHR**
- Patient *control*
Background – Medical Recordkeeping

- Manual Recordkeeping
- Digital Spreadsheets
- Private Clouds

?
Background – Distributed Health Records
Background – Blockchain

- **Peer-to-Peer (P2P);**
- **Distributed Ledger Technology (DLT);**

**Decentralised:** level of control over data;  
**Distributed:** data location (localization).

- **Healthcare adherence:** security (cryptography); **immutability**; pseudonymity (public-private keys).
- **Tamper-proof** (51% attack): **Consensus** protocols;
Background – Internet of Health Things (IoHT)
Background – IoHT

➢ **Points of contact** with the physical world; (CHRISTIDIS; DEVETSIKIOTIS, 2016).

➢ **Interconnected** devices exchanging and **processing** health data; (COSTA et al., 2018).

➢ **Sensors** collecting vital signs;

➢ **Constrained**: computing power, storage, and **energy availability**; (NOVO, 2018)
Background – Fog computing

- Local extension of the Cloud near the edge:
  - Services available locally;
  - Latency mitigation;
  - Things and Health Things are too constrained to run itself a complex consensus algorithms such as Proof-of-Work (PoW) and others, so Fog computing does the work!
School of Athens:
(Rafael Sanzio - 1510)
Related work

• Systematic Literature Review (SLR)
  – General research questions:

1. What is the taxonomy for PHRs in a Blockchain?

2. What are the challenges and open questions related to health records in a Blockchain?
Related Work – SLR Summary

Challenges

Opportunities
Related Work – Corpus

➢ Recent literature (~5 years)
Taxonomy

PHR in a Blockchain

SECURITY
- Alliance
  - GDFR
  - HIPAA
- GOVERNANCE
  - Open source communities
  - Regulatory Organizations (compliance)
- INTEROPERABILITY
  - Health Information Exchange (HIE)
  - Open standards
  - Smart Contracts
  - JSON
  - Plain text / Raw data
  - Proprietary
  - XML
  - PHR
  - HL7
  - OpenEHR
  - SNOMED
- PATIENT DATA
  - Standards
  - Anonymization and Data masking
  - Hashing
  - SHA 256
  - Cryptography
  - Notice
  - Time-stamping

SCALABILITY
- Block size
- Number of Nodes
- Number of Transactions
- Number of Users
- Chain
- Forks
- Sidechains (Side Layer)
- Edge Computing
- Cloud Computing
- Multi-Parametric devices
- Wearables
- Internet of Health Things

PRIVATE
- Archive node
- Blockchain as a Service (BaaS)
- Full node (heavyweight)
- Light node (lightweight)

Liveness
- Consensus Strategy
- Safety
- Proof of Activity
- Proof of Authority
- Proof of Burn
- Proof of Capacity
- Proof of Elapsed Time
- Byzantine Fault Tolerance
- Proof of Importance
- Proof of Stake
- Proof of Work

AUTHENTICATION
- Compound identities
- Pseudonym identity
- Identity
- Digital Signature
- Private key
- Public key
Research Opportunities

- **Patient-centric** model;
- **Health records distribution** enabling some level of interoperability among organizations and patients;
- **Immutable and tamper-proof** solution for PHR management;
- **Aim for real-time solutions** through fog computing architecture.
FOGCHAIN
ARCHITECTURAL MODEL


<< improvements >>
FogChain – Hospitals edge scenarios

Scenario 1 (Fogchain per room)

Scenario 2 (per ward)
FogChain – Macro view

Figure 5: FogChain architecture macro visualization.

LEGEND:
- IoHT devices
- Fogchain
- Blocks in chain
- Transactions
- Nighthub (IoT++) component (Protocols interop. and API calls)
- Blockchain Peers
- Data Transport (communication) via MQTT / COAP
- Visualization Requests
- Network members (Doctors, Nurses, Patients...)

Hyperledger Blockchain

Transactions

Genesis

Block #1

Block #N

Ordering / Consensus (algorithms and services)

Storage
1. **Protocols Interoperability:**
   - MQTT, COAP, HTTP conversions.

2. **Data Filtering and Validation:**
   - Data validation (prevent invalid data);
   - Filter to control what should be replicated;
   - Accumulate data for Batch.

3. **Transaction API:**
   - API to submit transactions to the Blockchain.

4. **Blockchain Peer:**
   - Local Blockchain network Peer;
FogChain – Single view

FogChain

Internal Components

- IoT++ protocols
- Data validation
- Filter + Replication
- node API

PEER

HYPERLEDGER

MQTT
CoAP
HTTP

IOT++ protocols
Data validation
Filter + Replication
node API
FogChain – IoT++ (Nightbus)

➢ IoT Protocols interoperability and conversions;

```json
{
  "foo": "test1",
  "baz": 42
}
```

Throughput benchmark results.

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<th>Protocol Combination</th>
<th>Throughput (msg/s)</th>
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Source: (SUAD et al., 2018)

https://github.com/fuadsaud/nightbus/blob/master/resources/fixtures/message.json
FogChain - Network Participants

Doctor

- doctorId: String
  name: String
  CRM: String
  specialties: String
  address: Address
  patients: ArrayList(Patient)

Patient

- cartaoSUS: string
  name: string
  dob: string
  address: Address
FogChain – Blockchain Consensus

➢ **Consensus** in Hyperledger Fabric chances into three phases: **Endorsement, Ordering, and Validation**:

- **Endorsing**
  - A transaction is executed and checked for correctness, thus endorsing it

- **Order**
  - Transaction is ordered through a pluggable consensus protocol

- **Validate**
  - Transaction is validated against application-specific endorsement policy and then pushed on the ledger
FogChain – Smart Contracts

Events Notification!
METHODOLOGY: SIMULATION AND BENCHMARK
Methodology – Simulation and Benchmark

➢ **Input:**
   - University of Queensland’s Vital signs dataset; (LIU; GORGES; JENKINS, 2012).

➢ **Multiple persistence configurations:**
   - Light, medium and heavy *simulation scenarios*;

➢ **Computational resources monitoring:**
   - CPU;
   - RAM;
Methodology – Simulation Hardware

- Ubuntu 16.04 (64-bit);
- Processor Intel Xeon E5-2620v4 2.1GHz 8c/16t;
- 32Gb RAM;
- HDD SAS 600Gb RAID 5 (10.000 RPM);
Methodology - Metrics

➢ **Throughput:**
  - The *rate* at which our implementation handles collected data and process transactions.

➢ **Latency:**
  - Time difference between the *one-way-delay* of selected packets within a stream of packets going from measurement point one (MP1) to measurement point two (MP2) end-to-end.
Benchmark - Simulation Sample PHR

Transaction block size: ~61Kb

```json
{
    "$class": "br.unisinos.uhospital.phr.MedicalRecord",
    "recordId": "1",
    "format": "ECG",
    "description": "0.9",
    "offchainDataLink": "https://gateway.ipfs.io/ipfs/b89eaac7e61417341b710b727768294d0e6a277b",
    "medicalHistory": "Hypertension",
    "allergies": "None",
    "currentMedication": "Atenolol",
    "smoking": false,
    "owner": "resource:br.unisinos.uhospital.ehr.Patient#123456789"
}
```
Preliminary Results

Figure 7: Overall benchmark results.

Axis Y: Transactions per second (TX/s)

Axis X: Persistence setup with batch size variation
Preliminary Results

Figure 8: CPU metrics during workload.

~ 6% CPU usage workload
Preliminary Results

Figure 9: Memory (RAM) metrics during workload.

+ 500Mb on heavy workload

~ 500Mb on regular workload
Conclusions

➢ **Fog computing** may play a big role in healthcare applications by improving local processing and storage capabilities **near the edge of hospital rooms**;

➢ **Blockchain** technology is not limited to the financial sector and may apply to other domains such as **healthcare**;

➢ **Open standards** adoption by healthcare industry to increase levels of **interoperability** between multiple systems and organizations;

➢ **More trials** must be carried out before placing our model in a real scenario.
Conclusions

- **Expected contributions:**
  - Patient-centric model;
  - Verification of the FogChain feasibility;
  - Publications and taxonomy;
  - Benchmarks;
  - Improve vital signs collecting process (IoHT);
  - Fog computing supporting low-latency models.
Research Limitations

➢ Very recent literature available;
➢ Focus only in PHR;
➢ Interoperability was not on initial scope and was discovered as challenge during SLR.
➢ Focus on server-side research and development for PHR management, and not on the client-side (data visualization, etc.);
Publications

• Accept (07-Jul-2019):

ISSN: 1460-4582
Online ISSN: 1741-2811
## Schedule of activities

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<th>Sep/19</th>
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Source: Elaborated by the author.
References

• **COSTA, C. A. da et al.** Internet of health things: toward intelligent vital signs monitoring in hospital wards. Artificial Intelligence In Medicine, [S.I.], 2018.


Thank You!

Questions?

Comments?

Suggestions?

André Mayer  Cristiano Costa  Rodrigo Righi  Alex Roehrs  Humberto Moura