Applied Computing Graduate Program

Master Proposal Qualifying Examination

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

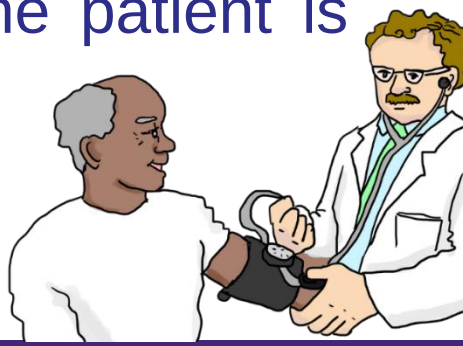
- How to improve **patients outcomes** regarding health data?
- How to **secure** and facilitate patients access and management to their own **personal** health records (**PHR**)?

- 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).



Introduction - Motivation

- 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

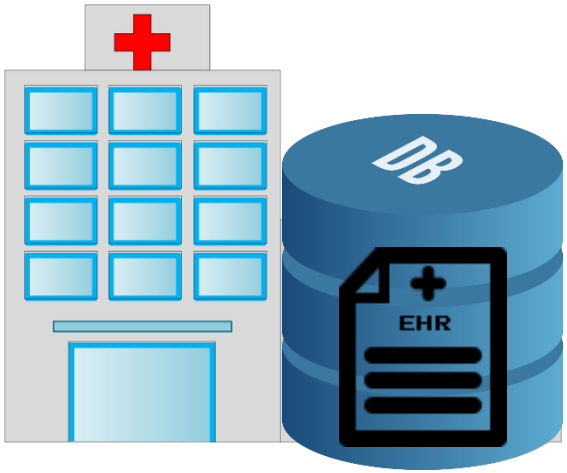
- ✓ **Taxonomy** classification into the state of the art;
- ✓ **Model** supporting **PHR** management with **fog computing** design integrating **IoHT** and **Blockchain**;
- ✓ **Prototype** implementation of a Blockchain with **smart contracts** support;
- ✓ **Benchmark** evaluation and analysis;
-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

PHR
IoT
Blockchain
EHR
Fog
Healthcare

BACKGROUND

Background – EHR vs PHR

EHR



Health providers **control**

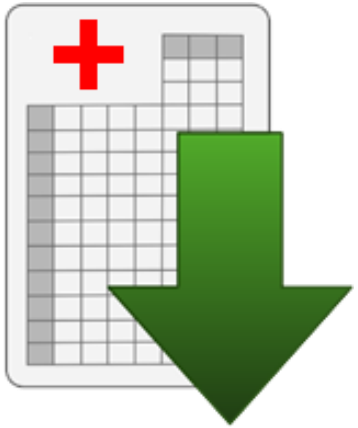
PHR

Patient **control**

Background – Medical Recordkeeping

Manual Recordkeeping

Digital Spreadsheets



Private Clouds

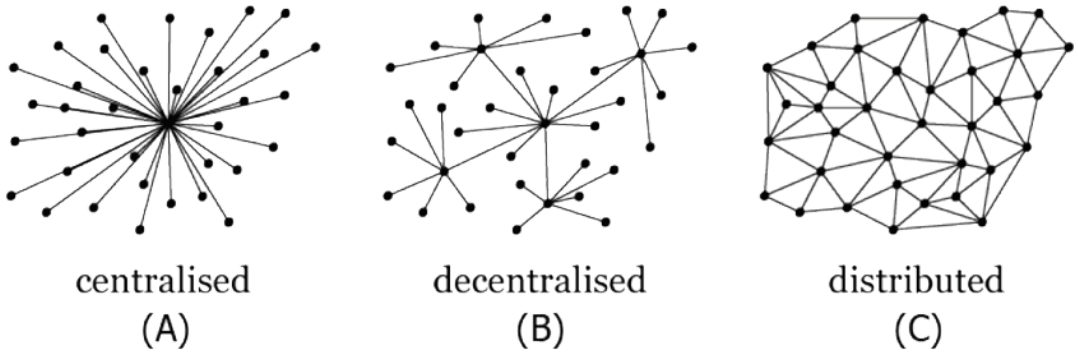
?

. . .

Background – Distributed Health Records

Background – Blockchain

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



Decentralised**:** level of **control** over data;

Distributed**:** data location (**localization**).

- **Healthcare aderency**: 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)

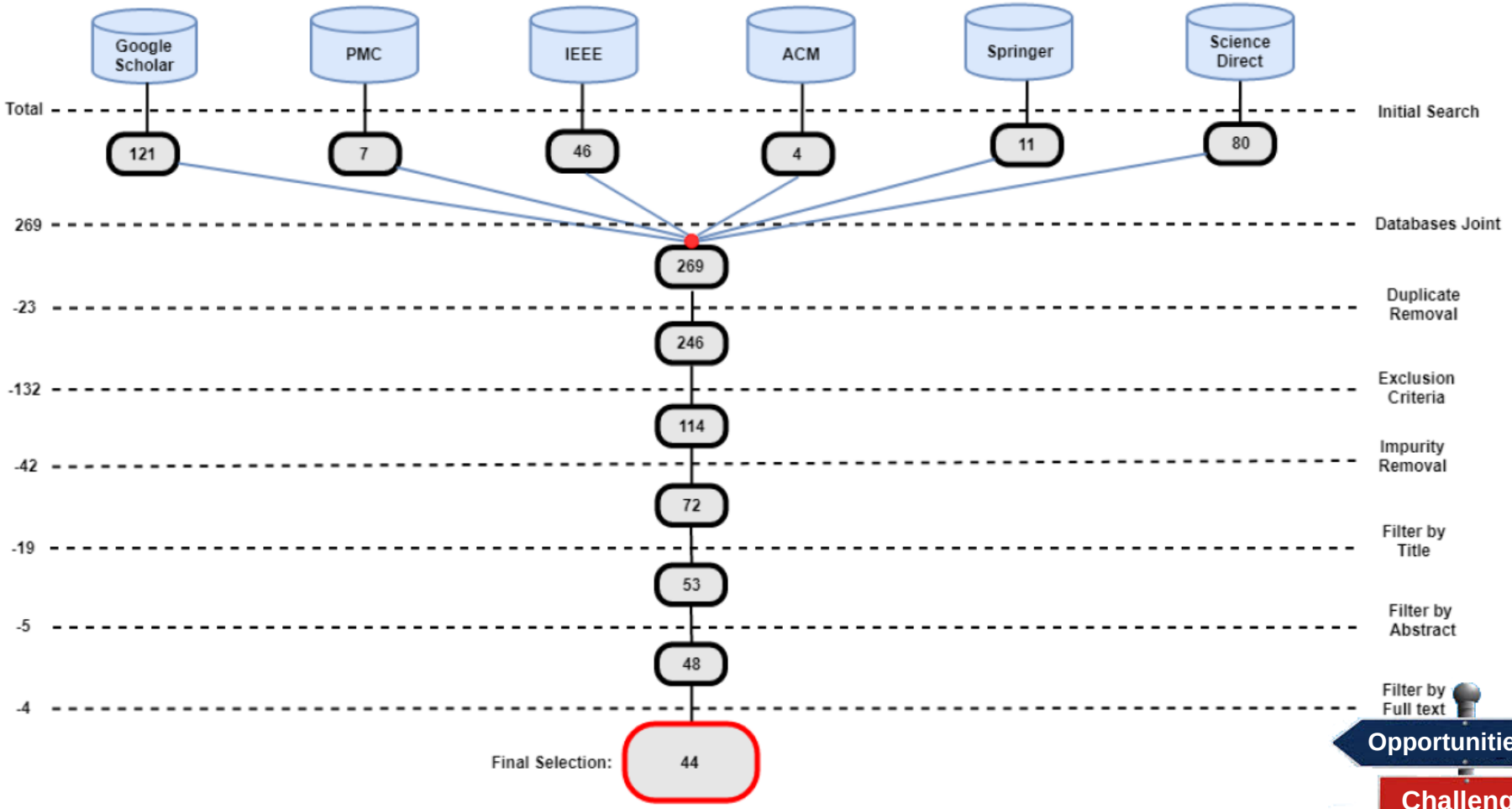
RELATED WORK

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

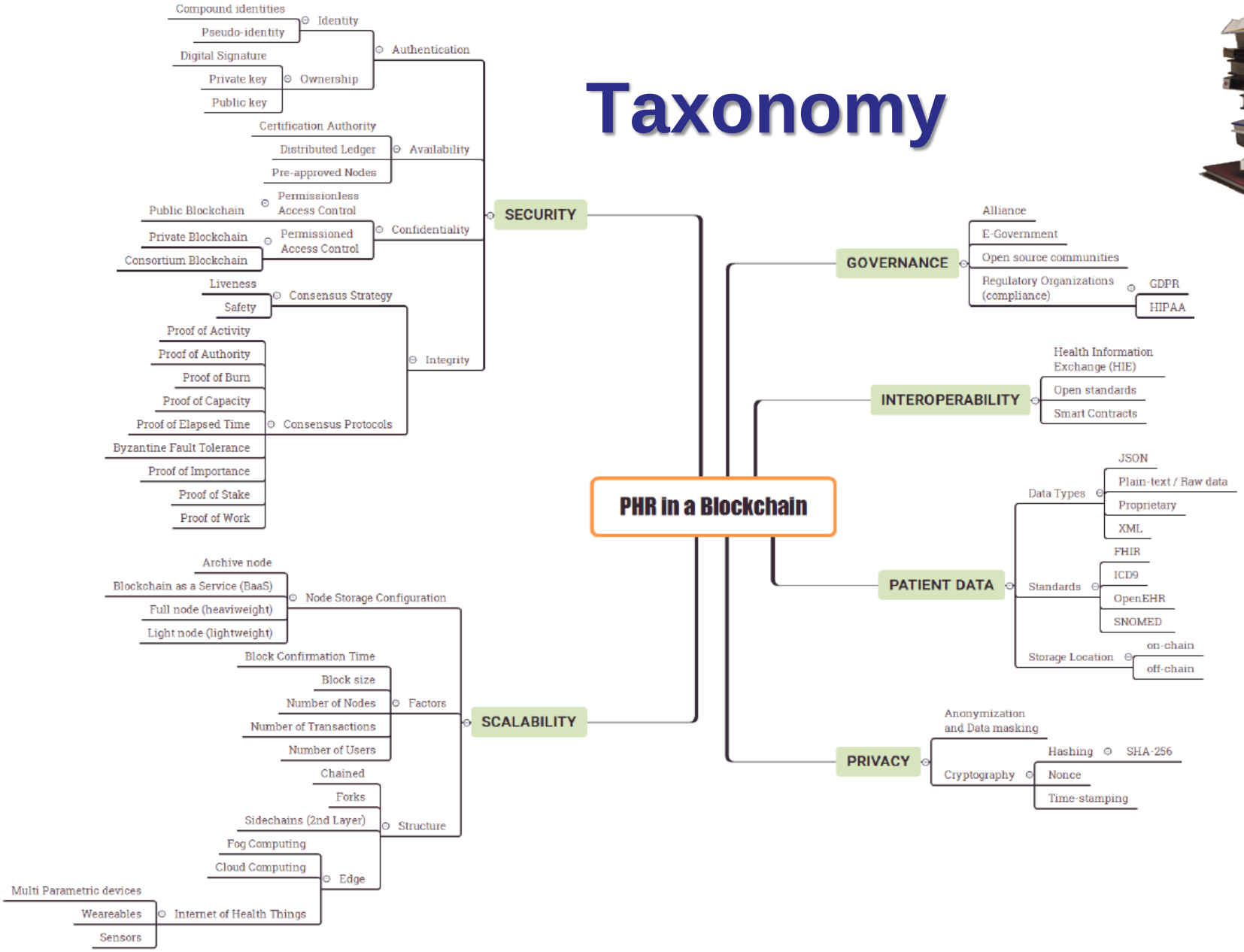


Related Work – Corpus

Reference	Authors	Year	Publisher	Type
A01	(LINN; KOO, 2016)	2016	HealthIt	Journal
A02	(EKBLAW et al., 2016)	2016	IEEE	Conference
A03	(YUE et al., 2016)	2016	Springer	Journal
A05	(NICHOL; BRANDT, 2016)	2016	Researchgate	Journal
A16	(HASHEMI et al., 2016)	2016	IEEE	Conference
A04	(ROEHRS; COSTA; ROSA RIGHI, 2017)	2017	Elsevier	Journal
A07	(YANG; YANG, 2017)	2017	NISK	Conference
A10	(SMITH; DHILLON, 2017)	2017	AMCIS	Conference
A11	(RABAH, 2017)	2017	MRJOURNALS	Journal
A12	(CHENG et al., 2018)	2017		
A13	(LIU et al., 2017)	2017		
A15	(ICHIKAWA; KASHIYAMA; UENO, 2017)	2017		
A19	(KSHETRI, 2017)	2017		
A21	(SHAE; TSAI, 2017)	2017		
A23	(KARAFILOSKI; MISHEV, 2017)	2017		
A24	(XIA et al., 2017)	2017		
A25	(THOMASON, 2017)	2017		
A26	(DUBOVITSKAYA et al., 2017)	2017		
A27	(LEMIEUX, 2017)	2017		
A29	(PRIISALU; OTTIS, 2017)	2017		
A35	(KUO; KIM; OHNO-MACHADO, 2017)	2017		
A06	(CYRAN, 2018)	2018		
A08	(PATEL, 2018)	2018		
A09	(DAGHER et al., 2018)	2018		
A14	(RIBITZKY et al., 2018)	2018		
A17	(ZHANG et al., 2018)	2018		
A18	(NIRANJANAMURTHY; NITHYA; JAGANNATHA, 2018)	2018	Springer	Journal
A20	(GUO et al., 2018)	2018	IEEE	Journal
A22	(FAN et al., 2017)	2018	IET Comm	Journal
A28	(MANNARO et al., 2018)	2018	IEEE	Conference
A30	(WANG; SONG, 2018)	2018	Springer	Journal
A31	(KLEINAKI et al., 2018)	2018	Elsevier	Journal
A32	(BANERJEE; LEE; CHOO, 2018)	2018	Elsevier and KeAi	Journal
A33	(GORDON; CATALINI, 2018)	2018	Elsevier	Journal
A34	(GROVER; KAR; DAVIES, 2018)	2018	Elsevier	Journal
A36	(JIANG et al., 2018)	2018	IEEE	Conference
A37	(MAMOSHINA et al., 2018)	2018	Impact Journals	Journal
A38	(ROMAN-BELMONTE; CORTE-RODRIGUEZ; RODRIGUEZ-MERCHAN, 2018)	2018	MEDKNOW Publications	Journal
A39	(BADR; GOMAA; ABD-ELRAHMAN, 2018)	2018	Elsevier	Journal
A40	(KELLER; KESSLER, 2018)	2018	IEEE	Conference
A41	(RAHMAN et al., 2019)	2019	IEEE	Journal
A42	(SILVA et al., 2019)	2019	Hindawi	Journal
A43	(TULI et al., 2019)	2019	Elsevier	Journal
A44	(SHEN; GUO; YANG, 2019)	2019	MDPI	Journal

- **Recent literature** (~5 years)

Taxonomy

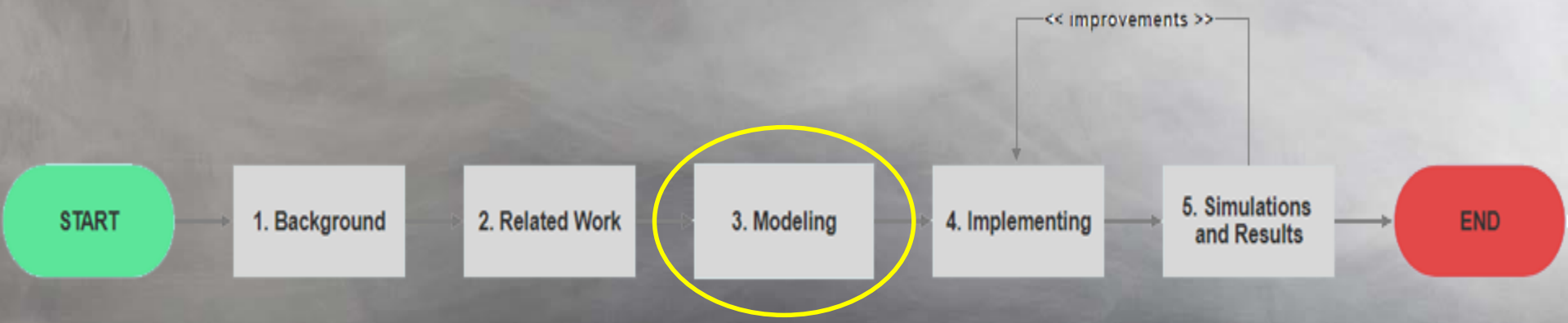


Research Opportunities

- **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.

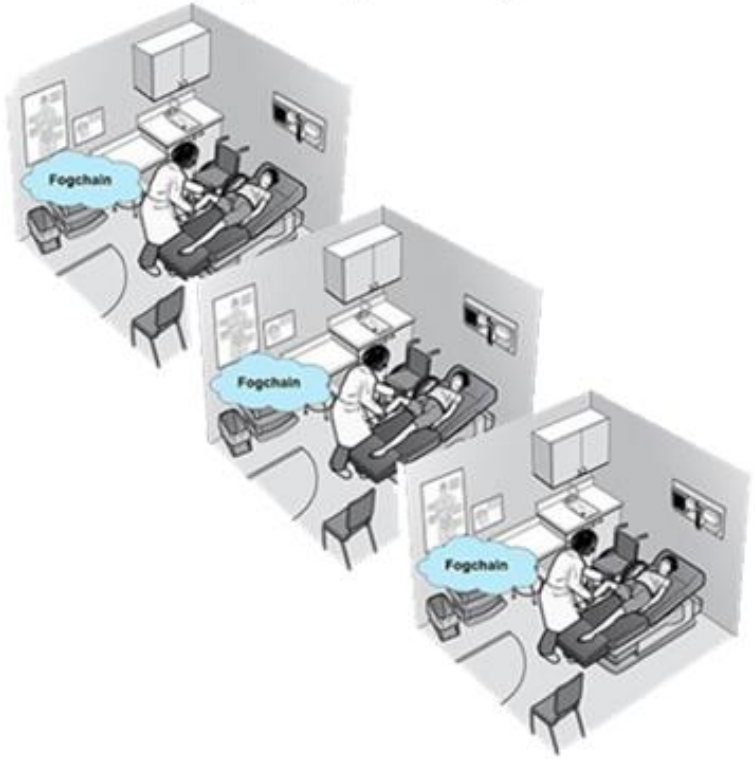
FOGCHAIN

ARCHITECTURAL MODEL



FogChain – Hospitals edge scenarios

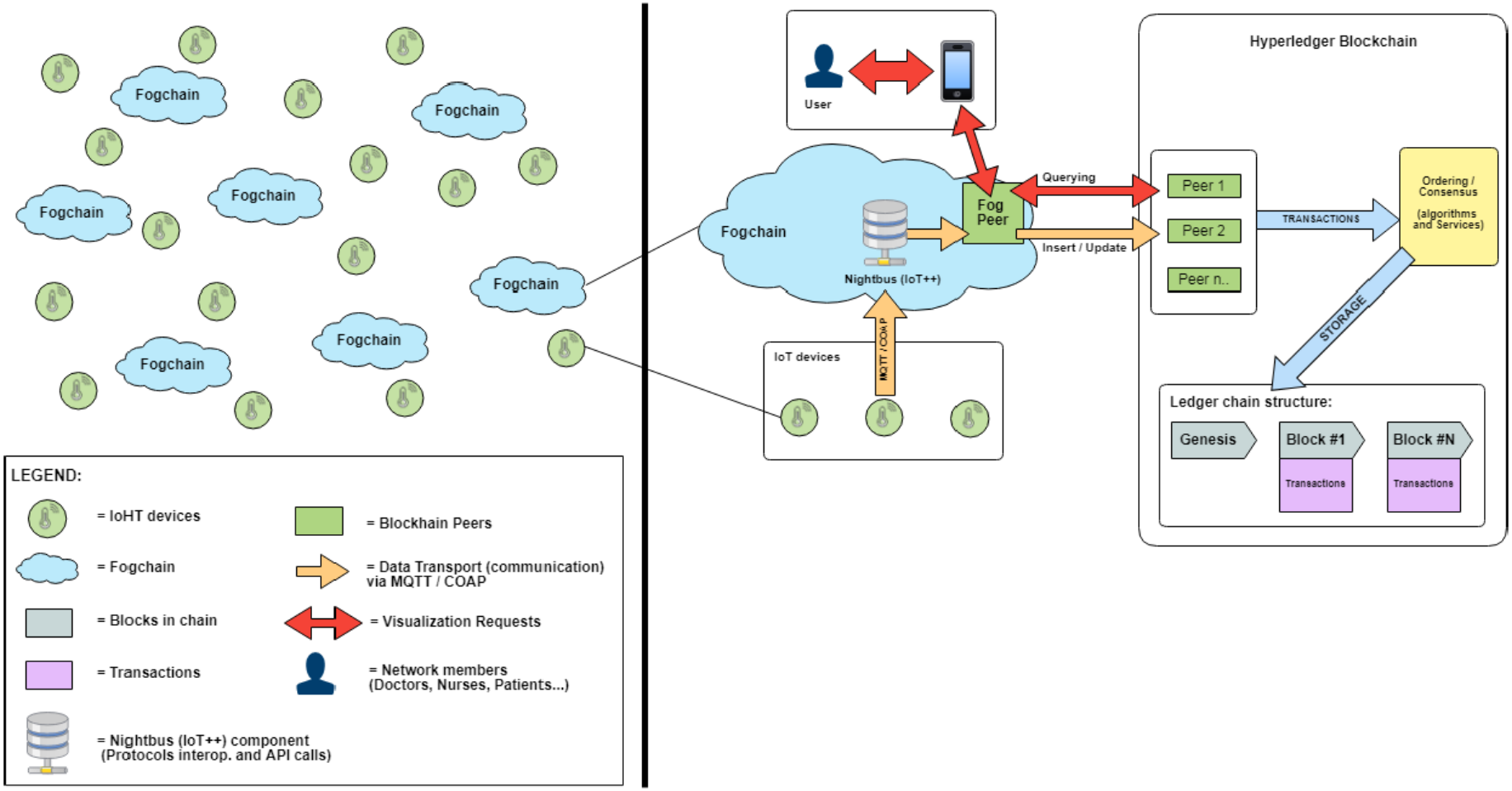
Scenario 1 (Fogchain per room)



Scenario 2 (per ward)

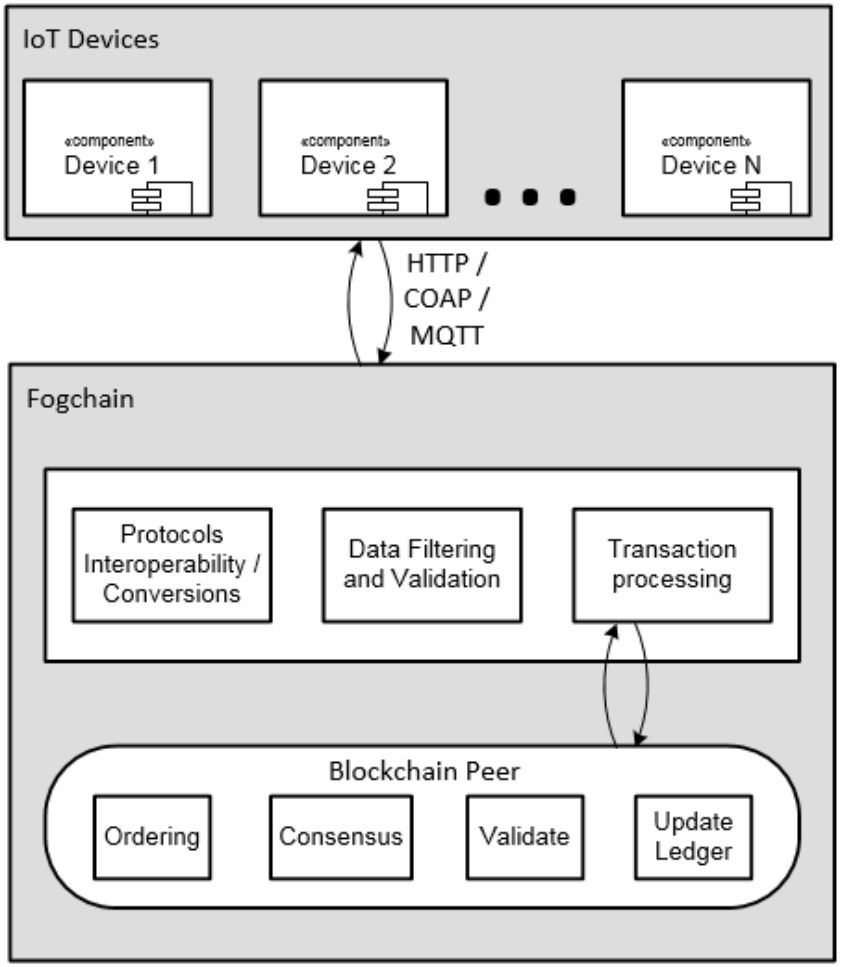
FogChain – Macro view

Figure 5: FogChain architecture macro visualization.



FogChain – Internal components

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

MQTT
CoAP
HTTP

FogChain

Internal Components

IoT++ protocols

Data validation

Filter + Replication

node API

PEER

HYPERLEDGER

FogChain – IoT++ (Nightbus)

- IoT Protocols interoperability and conversions;

Message size: 26 bytes

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

Throughput benchmark results.

MQTT - MQTT	CoAP - HTTP	HTTP - CoAP	MQTT - CoAP	MQTT - HTTP
53.51 msg/s	6.4 msg/s	35.08 msg/s	0.14 msg/s	49.89 msg/s

Source: (SUAD et al., 2018)

https://github.com/fuadsaud/nightbus/blob/master/resources/fixtures/message.json

FogChain - Network Participants

Doctor

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

Patient

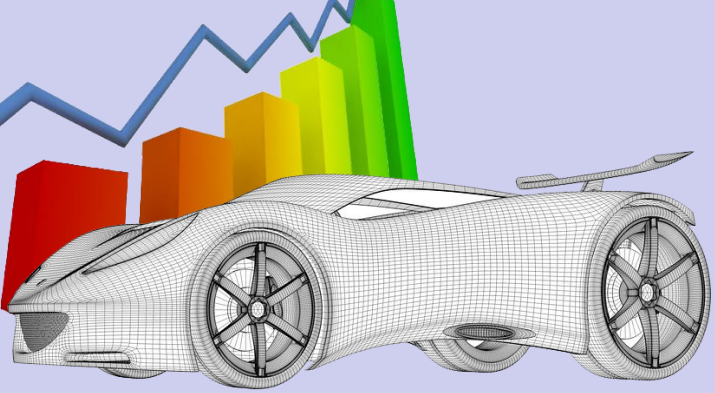
Patient
-cartaoSUS: string name: string dob: string address: Address

FogChain – Blockchain Consensus

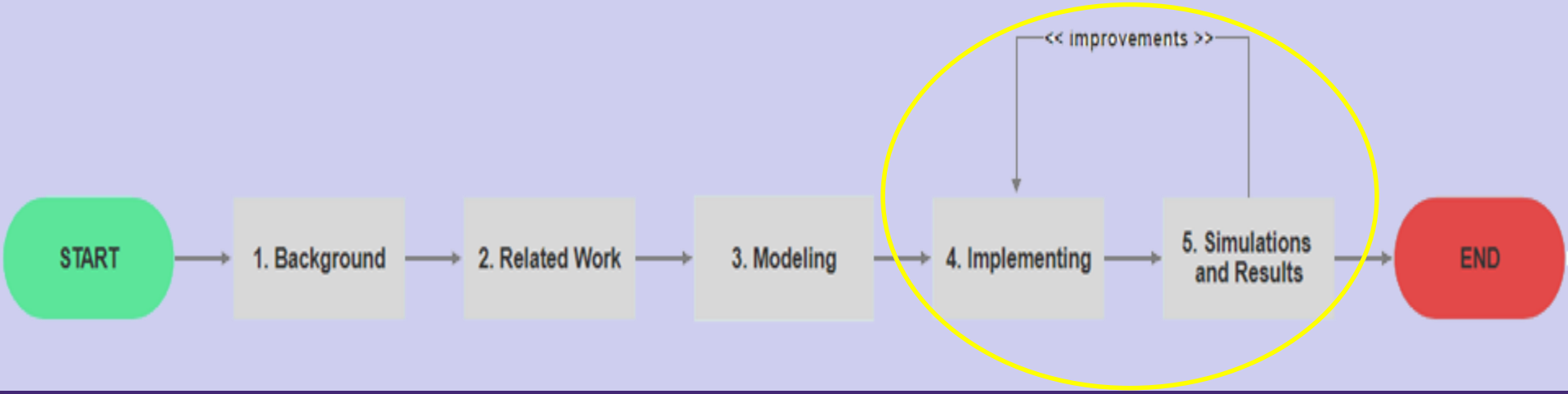
- **Consensus** in Hyperledger Fabric chances into three phases: **Endorsement**, **Ordering**, and **Validation**:

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 configutations:
  - Light, medium and heavy simulation scenarios;

- Computational resources monitoring:
  - **CPU**;
  - **RAM**;

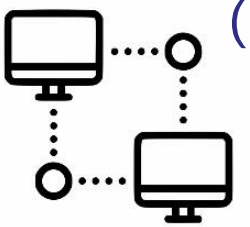
Methodology – Simulation Hardware

- 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.



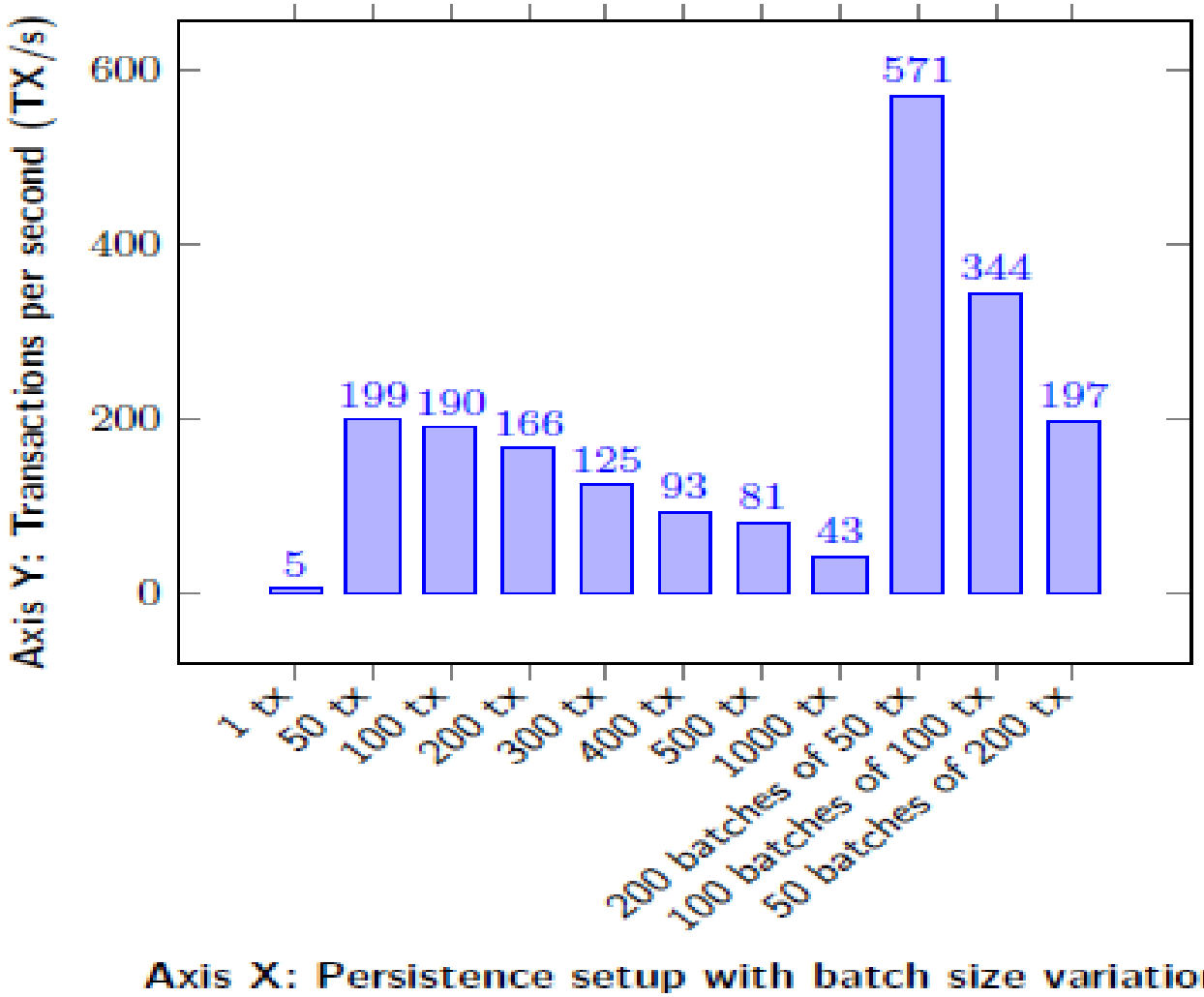
Benchmark - Simulation Sample PHR

Transaction block size: ~61Kb

```
{
  "$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"
}
```

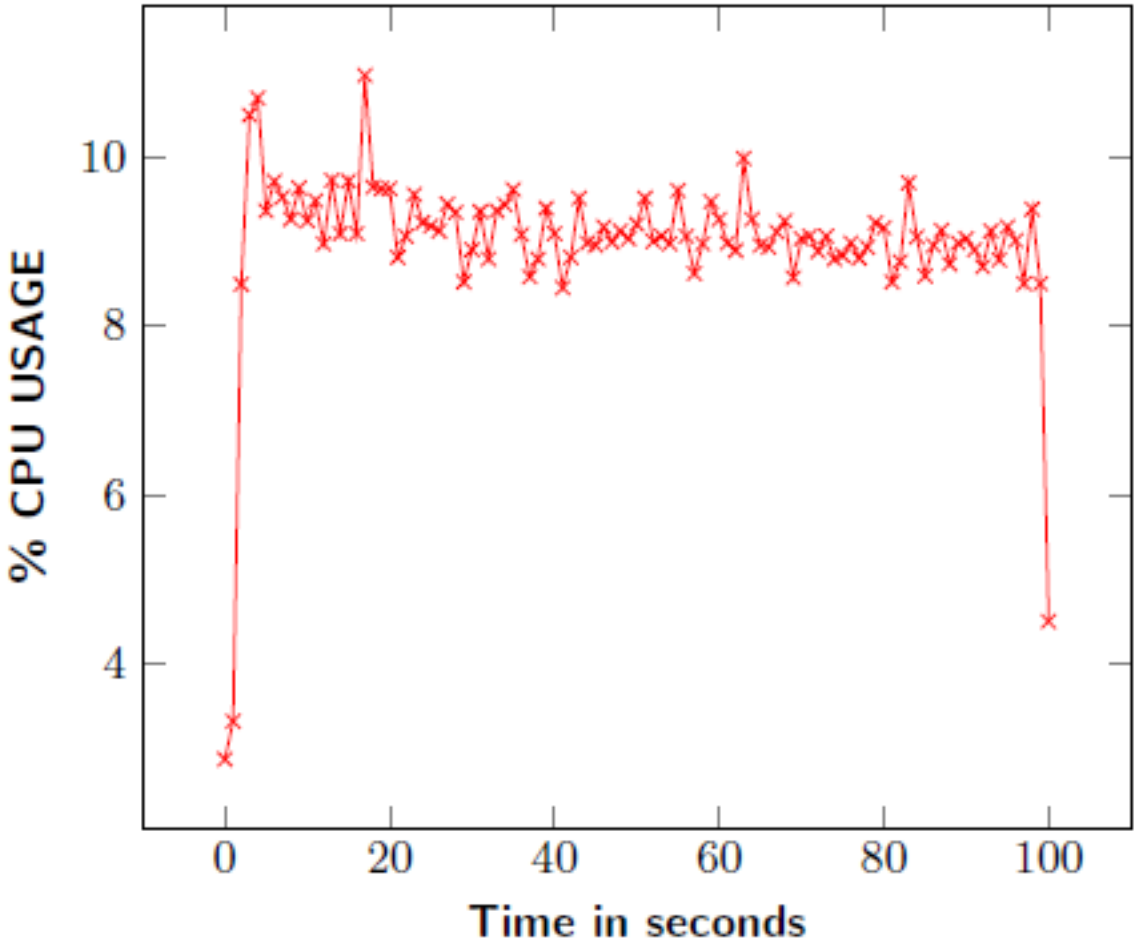
Preliminary Results

Figure 7: Overall benchmark results.



Preliminary Results

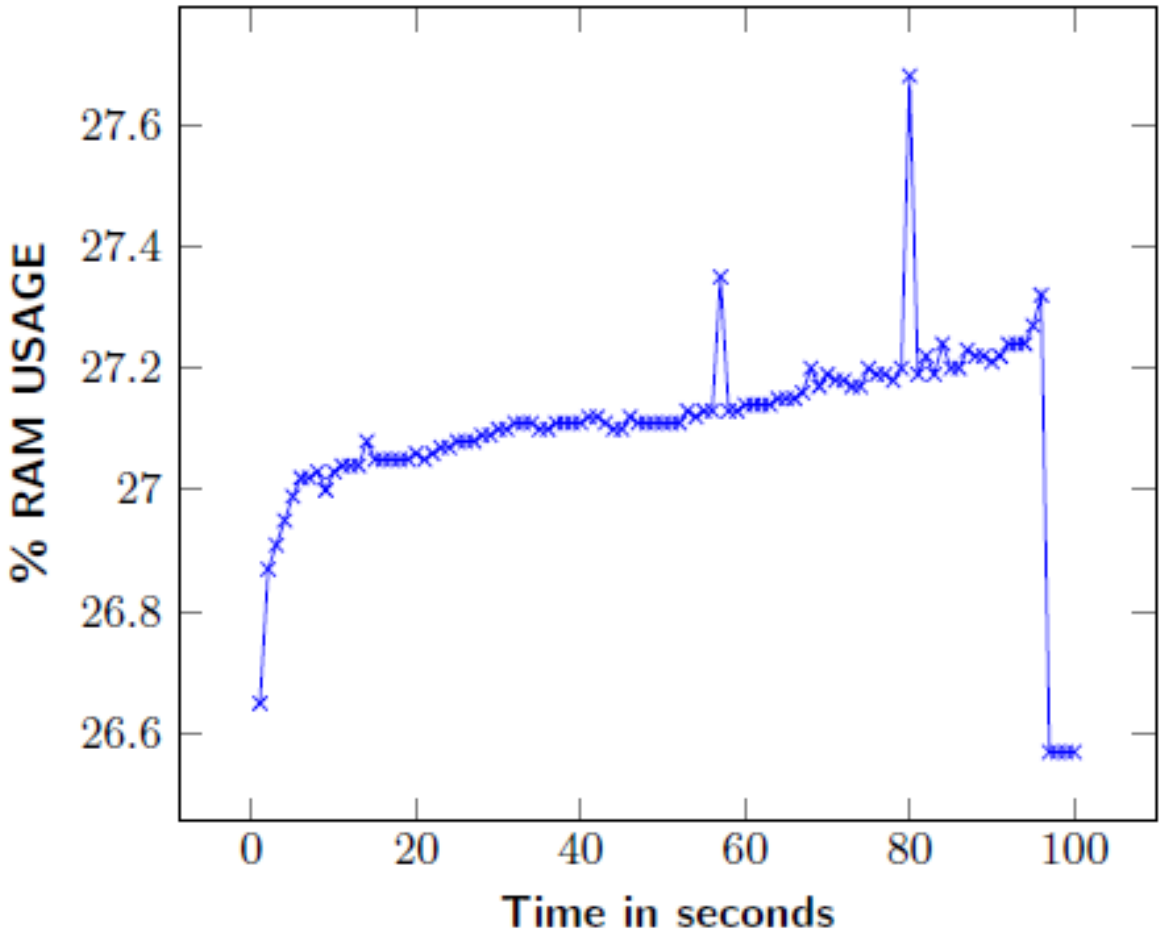
Figure 8: CPU metrics during workload.



~ 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):**
  - **MAYER, A.; COSTA, C. A. da; RIGHI, R. Electronic Health Records in a Blockchain: a systematic review.** Health Informatics Journal (HIJ).

ISSN: 1460-4582
Online ISSN: 1741-2811

Schedule of activities

Stage	Jul/19	Aug/19	Sep/19	Oct/19	Nov/19	Dec/19	Jan/20	Feb/20
Setup and configure Blockchain in a fog computing environment	✓							
Prototype modeling and implementation	✓	✓	✓					
Performance tests and evaluation		✓	✓					
Compile and analyze test results		✓	✓					
Second article submission		✓	✓	✓				
Write Dissertation	✓	✓	✓	✓	✓	✓		
Dissertation review						✓	✓	
Dissertation delivery							✓	
Third article submission						✓	✓	✓
Master's Defense								✓

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.l.], 2018.
- **SHARMA, P. K.; CHEN, M.-Y.; PARK, J. H.** A software defined fog node based distributed blockchain cloud architecture for iot. IEEE Access, [S.l.], v. 6, p. 115–124, 2018.
- **LIU, D.; GORGES, M.; JENKINS, S. A.** University of queensland vital signs dataset. Anesthesia & Analgesia, [S.l.], v. 114, n. 3, p. 584–589, mar 2012.
- **CHRISTIDIS, K.; DEVETSIKIOTIS, M.** Blockchains and smart contracts for the internet of things. Ieee Access, [S.l.], v. 4, p. 2292–2303, 2016.
- **NOVO, O.** Blockchain meets iot: an architecture for scalable access management in iot. IEEE Internet of Things Journal, [S.l.], v. 5, n. 2, p. 1184–1195, 2018.
- **SUAD, F. et al.** Exploring extensibility and interoperability in the internet of things landscape. In: INTERNATIONAL CONFERENCE ON WWW/INTERNET 2018, 17., 2018, 2018, Budapeste. PROCEEDINGS OF THE INTERNATIONAL CONFERENCES ON WWW/INTERNET 2018 AND APPLIED COMPUTING 2018. Lisboa. Anais. . . IADIS, 2018. p. 339–343.

Thank You!


André Mayer


Cristiano Costa


Rodrigo Righi


Alex Roehrs


Humberto Moura