A PLATFORM FOR ANALYZING PAYMENT CHANNEL NETWORKS IN SUPPORTING REAL-WORLD PAYMENT PATTERNS*

5th Distributed Ledger Technology Workshop (DLT 23) - May 26th, 2023 - Bologna, Italy

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01 INTRODUCTION
Background, motivation, and problem statement

02 RELATED WORK
Main challenges and our contributions

03 RESEARCH APPROACH
Research questions, system design and investigation

04 CONCLUSION
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BACKGROUND

PAYMENT CHANNEL NETWORKS
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PAYMENT CHANNEL NETWORKS
MOTIVATION

INTERESTING CASH-LIKE FEATURES

PCNs provide payments with the following features:
MOTIVATION

INTERESTING CASH-LIKE FEATURES

PCNs provide payments with the following features:

- Instantaneous
- Peer-to-peer
- End-to-end encrypted
MOTIVATION

INTERESTING CASH-LIKE FEATURES

PCNs provide **payments** with the following features:

- Instantaneous
- Peer-to-peer
- End-to-end encrypted

But **are PCNs scalable** in terms of Transactions Per Second (TPS)?
PROBLEM STATEMENT: THE TRADE-OFF
LOCKED LIQUIDITY – PAYMENT SUCCESS RATE

A payment succeed iff:
- A path connecting the sender and the receiver exists,
PROBLEM STATEMENT: THE TRADE-OFF
LOCKED LIQUIDITY – PAYMENT SUCCESS RATE

A payment succeed iff:
• A **path** connecting the sender and the receiver exists,
• s.t. each channel along the path has **sufficient balance** to complete the transaction.

Alice to Bob: 2 €
PROBLEM STATEMENT: THE TRADE-OFF

LOCKED LIQUIDITY – PAYMENT SUCCESS RATE

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PROBLEM STATEMENT

CHANNEL LIQUIDITY – PAYMENT SUCCESS RATE TRADE-OFF

Infinite capacity channels may be desired, however liquidity implies costs, e.g.:
- Interest charges;
- Opportunity costs.
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CHANNEL LIQUIDITY – PAYMENT SUCCESS RATE TRADE-OFF

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PROBLEM STATEMENT: THE TRADE-OFF
LOCKED LIQUIDITY – PAYMENT SUCCESS RATE
The liquidity cost may push the network to a hub-and-spoke distribution, where a few nodes, called Liquidity Service Providers (LSPs), open channels to end users to increase their:

- **Inbound** capacity;
- **Reachability**.
OUR IDEA

A PCN AS A DIGITAL PAYMENTS SYSTEM
OUR IDEA

A PCN AS A DIGITAL PAYMENTS SYSTEM

We envision a 2-tiers LSP topology:
OUR IDEA

A PCN AS A DIGITAL PAYMENTS SYSTEM

We envision a 2-tiers LSP topology:

- **t1-LSP**: provides liquidity to tier-2 LSPs (e.g. Central Banks);
We envision a 2-tiers LSP topology:

- **t1-LSP**: provides liquidity to tier-2 LSPs (e.g. Central Banks);
- **t2-LSP**: opens channels toward multiple end-users (e.g. Commercial Banks);
OUR IDEA
A PCN AS A DIGITAL PAYMENTS SYSTEM
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A PCN AS A DIGITAL PAYMENTS SYSTEM

Advantages:
OUR IDEA

A PCN AS A DIGITAL PAYMENTS SYSTEM

Advantages:
- Cryptographically-enforced trust-less payments
OUR IDEA

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- Reuse existing protocols and applications (LN)
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A PCN AS A DIGITAL PAYMENTS SYSTEM

Advantages:
- Cryptographically-enforced trust-less payments
- Reuse existing protocols and applications (LN)
- New scalability opportunities to explore (e.g. topologies, cost, etc.)
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STUDYING PCNs NETWORK ASPECTS

THE CHALLENGES
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Assuming a **fully private setting**, the two main challenges are:
STUDYING PCNs NETWORK ASPECTS

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Assuming a **fully private setting**, the two main challenges are:

- the lack of knowledge of **channel balances**;
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Assuming a fully private setting, the two main challenges are:

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- the impossibility to measure the payment success rate.
STUDYING PCNs NETWORK ASPECTS

THE CHALLENGES

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- the lack of knowledge of channel balances;
- the impossibility to measure the payment success rate.

Simulations used in many studies:
STUDYING PCNs NETWORK ASPECTS

THE CHALLENGES

Assuming a **fully private setting**, the two main challenges are:

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**Simulations** used in many studies:

- *Lange et al.* [1] assumes **three** different transactions **volumes**;
STUDYING PCNs NETWORK ASPECTS

THE CHALLENGES

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- *Lange et al. [1]* assumes three different transactions volumes;
- *Cordi [2]* simulates transactions from a **partner bank database**.
STUDYING PCNs NETWORK ASPECTS

THE CHALLENGES

Assuming a **fully private setting**, the two main challenges are:

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**Simulations** used in many studies:

- *Lange et al.* [1] assumes **three** different transactions **volumes**;
- *Cordi* [2] simulates transactions from a **partner bank database**;
- *Beres et al.* [3] uses **assumptions** based on LN node owners **blog posts**.
STUDYING PCNs NETWORK ASPECTS
OUR CONTRIBUTION

Assuming a **fully private setting**, the two main challenges are:

- the lack of knowledge of **channel balances**;
- the **impossibility** to measure the **payment success rate**.

Using **simulation**, we want to analyse:

- The efficiency of **hub-and-spoke topologies**, aiming to understand whether and how their **liquidity needs** can support volumes of payments comparable with those of **national currencies**.
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RESEARCH APPROACH

RESEARCH QUESTIONS
RESEARCH APPROACH

RESEARCH QUESTIONS

**RQ1.**
What would be the required **LSP liquidity** to support a **given target of transactions/second** with lower bounds on **payments success rate**?
RESEARCH APPROACH

RESEARCH QUESTIONS

**RQ1.** What would be the required LSP liquidity to support a given target of transactions/second with lower bounds on payments success rate?

**RQ2.** How would some liquidity optimisation techniques (e.g. multiparty payments) impact the liquidity needs and payments success rate?
RESEARCH APPROACH

RESEARCH QUESTIONS

**RQ1.** What would be the required **LSP liquidity** to support a **given target of transactions/second** with lower bounds on **payments success rate**?

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**RQ3.** What would be the impact of **node failures** on payment success rate?
RESEARCH APPROACH

RESEARCH QUESTIONS

RQ1. What would be the required LSP liquidity to support a given target of transactions/second with lower bounds on payments success rate?

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RQ4. Given a PCN topology and the total volume of payments, how does changing payment load distribution impact on payment success rate?
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RQ5. What kind of privacy challenges would such an almost-fixed topology need to consider?
SYSTEM DESIGN

4 MAIN COMPONENTS

- PCN TOPOLOGY GENERATOR
- CALIBRATOR
  Compute optimal channel capacities
- PAYMENTS SIMULATOR
- TXs GENERATOR
SYSTEM DESIGN

01. PCN TOPOLOGY GENERATOR

3 types of nodes:
- Tier1-LSP
- Tier2-LSP
- End-user (user or merchant)
SYSTEM DESIGN

01. PCN TOPOLOGY GENERATOR

5 subnetworks:
- T1-LSP – T1-LSP
- T1-LSP – T2-LSP
- T2-LSP – T2-LSP
- T2-LSP – End-user
- End-user – End-user
SYSTEM DESIGN

01. PCN TOPOLOGY GENERATOR

INPUT:
- Number of nodes
- Ratios among node types

For each subnetwork
- Graph model (e.g. clique, Watts-Strogatz, Erdős-Rényi, etc.)
- Capacity distribution (e.g. uniform, exponential, etc.)
SYSTEM DESIGN

01. PCN TOPOLOGY GENERATOR

OUTPUT:
- Graph description (nodes and edges)
SYSTEM DESIGN

02. TRANSACTIONS GENERATOR

INPUT
- Set of nodes
- Number of txs
- Rate of txs
- Statistics from ECB SPACE 2022 Study on payments attitudes [4] about:
  - TX type (PoS, P2P, Online)
  - TX amounts
02. TRANSACTIONS GENERATOR

**OUTPUT**
- Transactions file containing:
  - sender
  - receiver
  - tx type
  - amount
  - start time
03. PAYMENTS SIMULATOR

An extension of CLoTH [5], a PCN simulator that mimics the routing and HTLC mechanics used in LN.
SYSTEM DESIGN

03. PAYMENTS SIMULATOR

INPUT

Settings configuration file
TXs

PCN TOPOLOGY GENERATOR

CALIBRATOR
Compute optimal channel capacities

PAYMENTS SIMULATOR

OUTPUT

Graphs and analysis
03. PAYMENTS SIMULATOR

SYSTEM DESIGN

OUTPUT
- Performance metrics:
  - Payments success rate
  - Average payment time
  - etc.

PCN TOPOLOGY GENERATOR
CALIBRATOR

PAYMENTS SIMULATOR

TXs GENERATOR
04. CALIBRATOR

**GOAL**
Optimize the PCN by identifying the minimum channels’ liquidity that satisfies a given lower bound payment success rate.

**CALIBRATOR**
Compute optimal channel capacities.
**SYSTEM DESIGN**

**COMPONENTS INTERACTION**

CALIBRATOR

**TASKS:**
- Sample the parameters for the subnetworks capacities distributions
- Run the simulator using the newly generated files
- Compute loss function on simulator output statistics
SYSTEM DESIGN

COMPONENTS INTERACTION

PCN TOPOLOGY GENERATOR

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**TXs GENERATOR**

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**PAYMENTS SIMULATOR**
**SYSTEM DESIGN**

**COMPONENTS INTERACTION**

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**PAYMENTS SIMULATOR**
A Platform for Analyzing Payment Channel Networks in Supporting Real-world Payment Patterns
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SYSTEM DESIGN
COMPONENTS INTERACTION

PCN TOPOLOGY GENERATOR
TXs GENERATOR
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PAYMENTS SIMULATOR

ITERATIVE PROCESS
SYSTEM DESIGN

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PAYMENTS SIMULATOR

ITERATIVE PROCESS
RESEARCH APPROACH

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RQ3. What would be the impact of node failures on payment success rate?

RQ4. Given a PCN topology and the total volume of payments, how does changing payment load distribution impact on payment success rate?

RQ5. What kind of privacy challenges would such an almost-fixed topology need to consider?
RESEARCH APPROACH

ADDRESSING THE RESEARCH QUESTIONS

RQ1. What would be the required LSP liquidity to support a given target of transactions/second with lower bounds on payments success rate?

💡 Once the balances are optimized, the required total system liquidity can be analyzed.

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RESEARCH APPROACH

ADDRESSING THE RESEARCH QUESTIONS

💡 Enabling additional CLoTH features: multi-path payment and node failures.

**RQ2.** How would some liquidity optimisation techniques (e.g. multiparty payments) impact the liquidity needs and payments success rate?

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Given a PCN topology and the total volume of payments, how does changing payment load distribution impact on payment success rate?

💡 Replace ECB SPACE 2022 study statistics with other assumptions in the TX Generator.

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RESEARCH APPROACH

ADDRESSING THE RESEARCH QUESTIONS

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💡 Requires a deeper literature review, and an investigation of leaked information in fixed topologies

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CONCLUSION

ENRICHING THE WORLD REVOLVING AROUND PCNS
CONCLUSION

ENRICHING THE WORLD REVOLVING AROUND PCNS

We aim to:

- Provide a better understanding of **PCN scalability**;
- Analyse the feasibility of using a PCN as a **possible retail CBDC implementation**, where central banks and commercial banks could play the role of LSPs.
REFERENCES


(2) Simulating high-throughput cryptocurrency payment channel networks. Christopher Neal Cordi. 2017. https://hdl.handle.net/2142/99319


(4) Study on the payment attitudes of consumers in the euro area (SPACE). ECB Surveys. 2022.

THANK YOU

QUESTIONS?

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