BANCA D'ITALIA
EUROSISTEMA

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

Marco Benedetti, Giuseppe Galano, Sara Giammusso, Matteo Nardelli
{first name}.{last name}@bancaditalia.it, giuseppe.galano2@bancaditalia.it

*All views and opinions are those of the speaker(s) and do not necessarily reflect the position of Bank of Italy

ART
Applied Research Team

BANCA D'ITALIA
EUROSISTEMA

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

Marco Benedetti, Giuseppe Galano, Sara Giammusso, Matteo Nardelli
{first name}.{last name}@bancaditalia.it, giuseppe.galano2@bancaditalia.it

*All views and opinions are those of the speaker(s) and do not necessarily reflect the position of Bank of Italy

A R T
Applied Research Team

AGENDA

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**

AGENDA

01 INTRODUCTION
Background, motivation, and problem statement

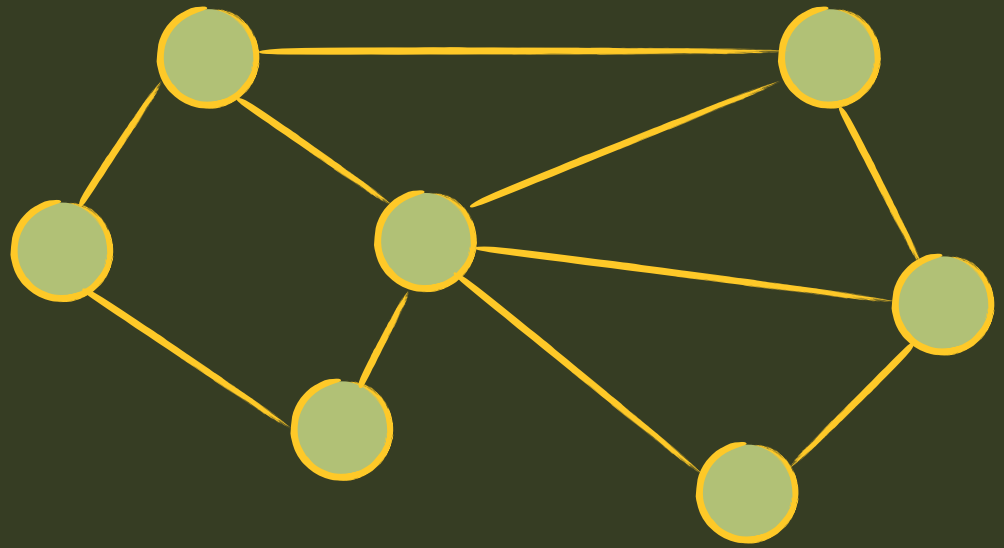
02 RELATED WORK
Main challenges and our contributions

03 RESEARCH APPROACH
Research questions, system design, and investigation

04 CONCLUSION

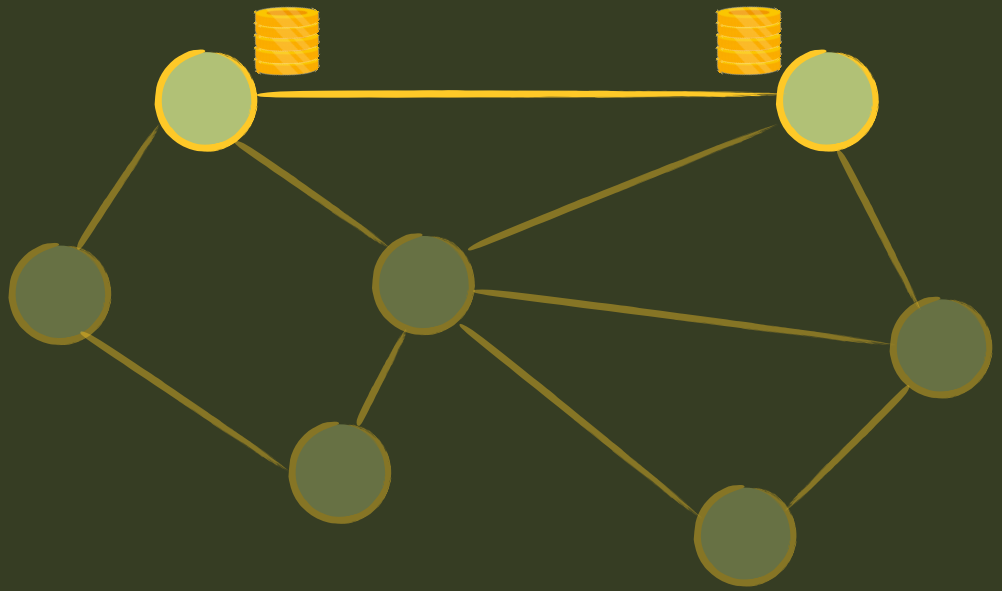
BACKGROUND
PAYMENT CHANNEL NETWORKS

BACKGROUND
PAYMENT CHANNEL NETWORKS



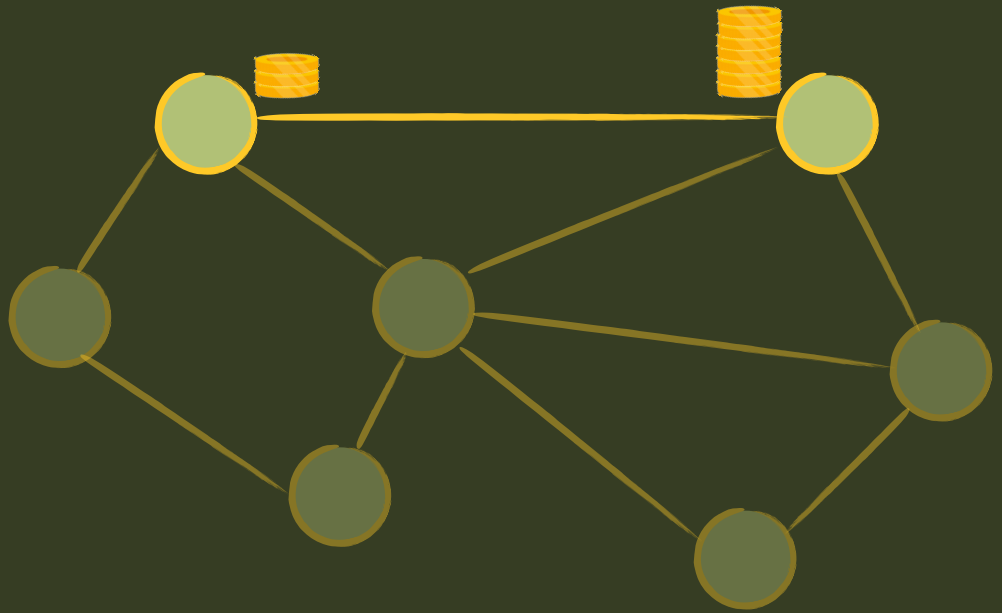
BACKGROUND

PAYMENT CHANNEL NETWORKS



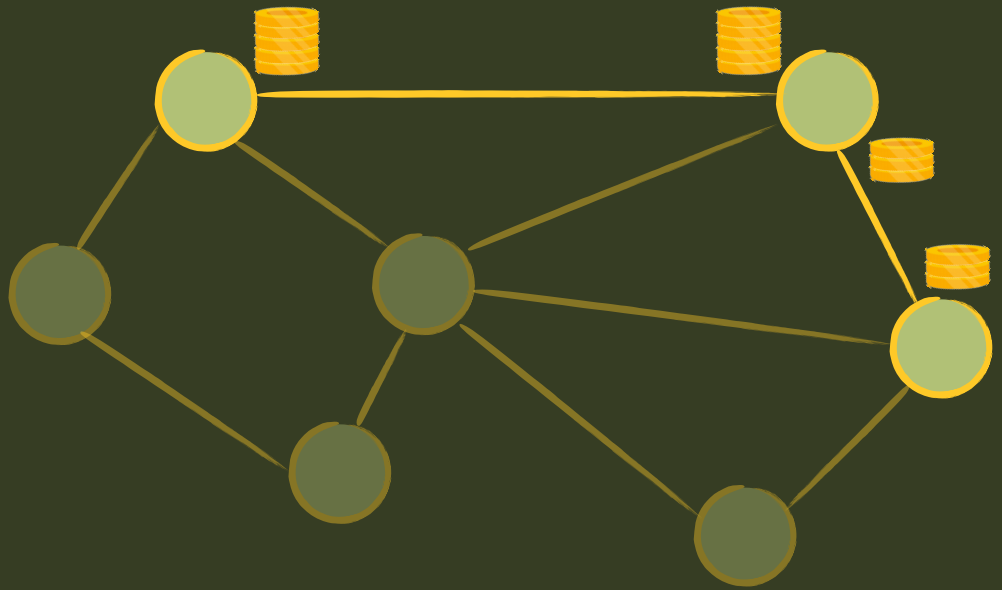
BACKGROUND

PAYMENT CHANNEL NETWORKS



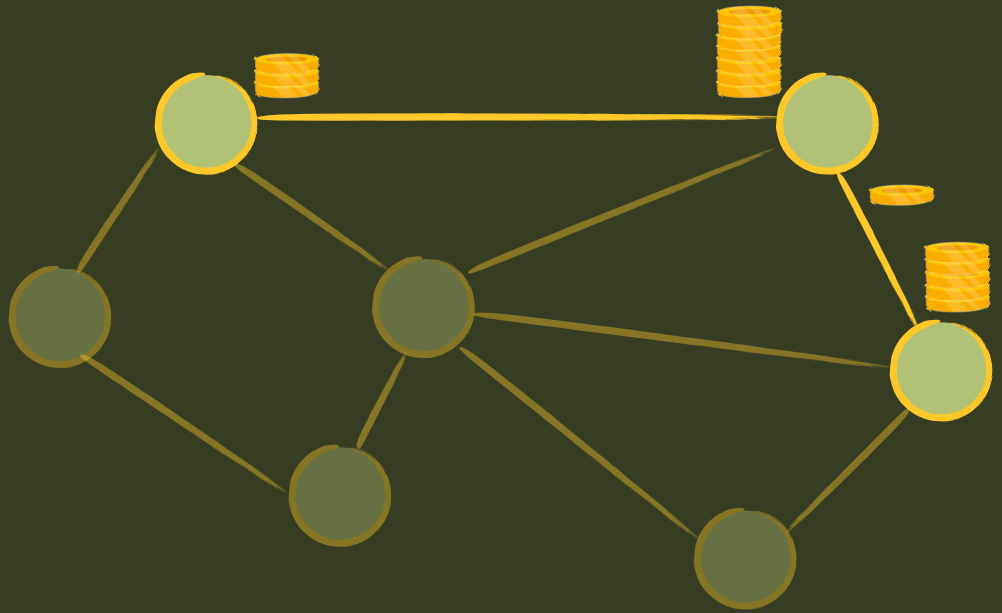
BACKGROUND

PAYMENT CHANNEL NETWORKS



BACKGROUND

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:

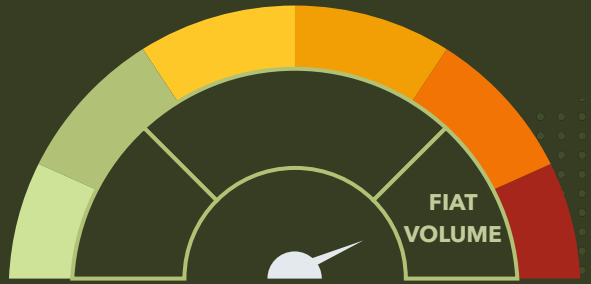
- **Instantaneous**
- **Peer-to-peer**
- **End-to-end encrypted**

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)?

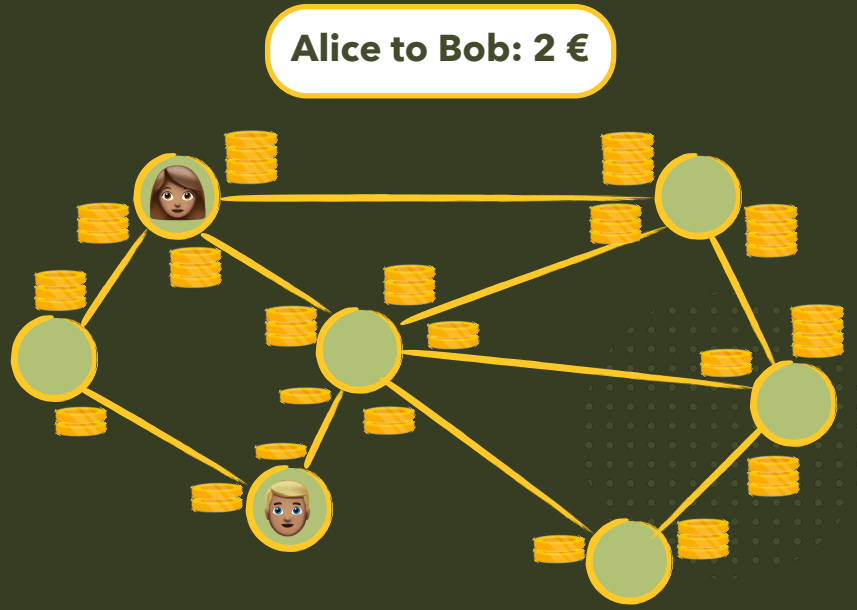


PROBLEM STATEMENT: THE TRADE-OFF

LOCKED LIQUIDITY – PAYMENT SUCCESS RATE

A payment succeed iff:

- A **path** connecting the sender and the receiver exists,

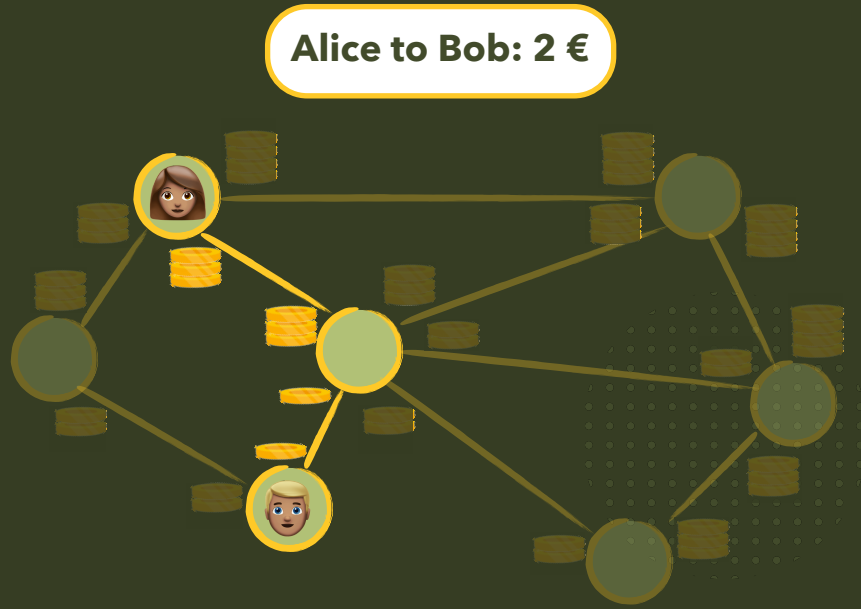


PROBLEM STATEMENT: THE TRADE-OFF

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.

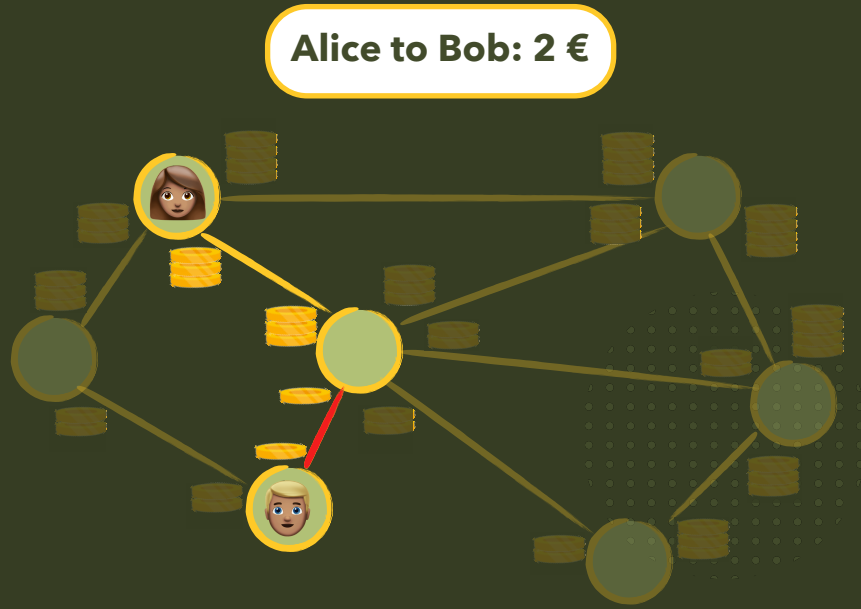


PROBLEM STATEMENT: THE TRADE-OFF

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.



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.

PROBLEM STATEMENT

CHANNEL LIQUIDITY – PAYMENT SUCCESS RATE TRADE-OFF

Infinite capacity channels may be desired, however liquidity implies **costs**, e.g.:

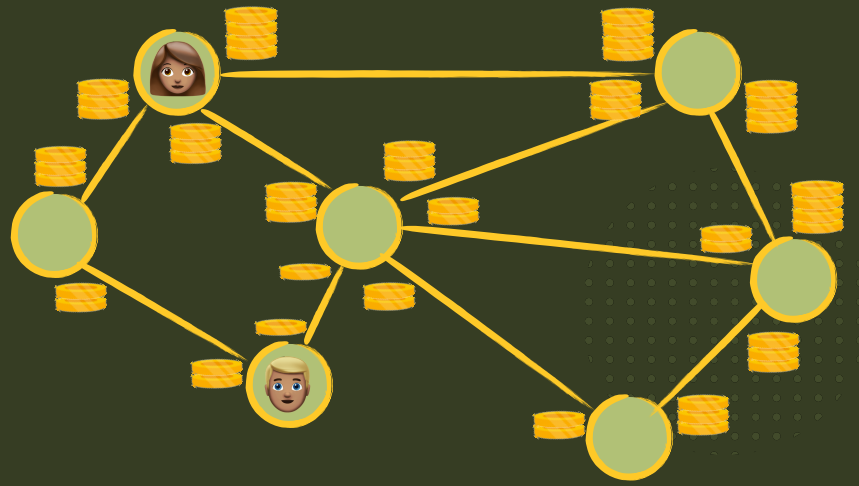
- Interest charges;
- Opportunity costs.

PROBLEM STATEMENT: THE TRADE-OFF

LOCKED LIQUIDITY – PAYMENT SUCCESS RATE

Infinite capacity channels may be desired, however liquidity implies **costs**, e.g.:

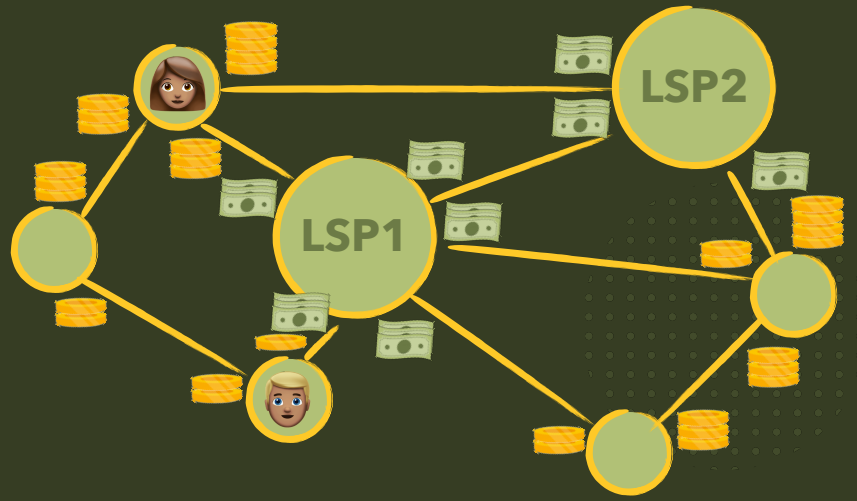
- Interest charges;
- Opportunity costs.



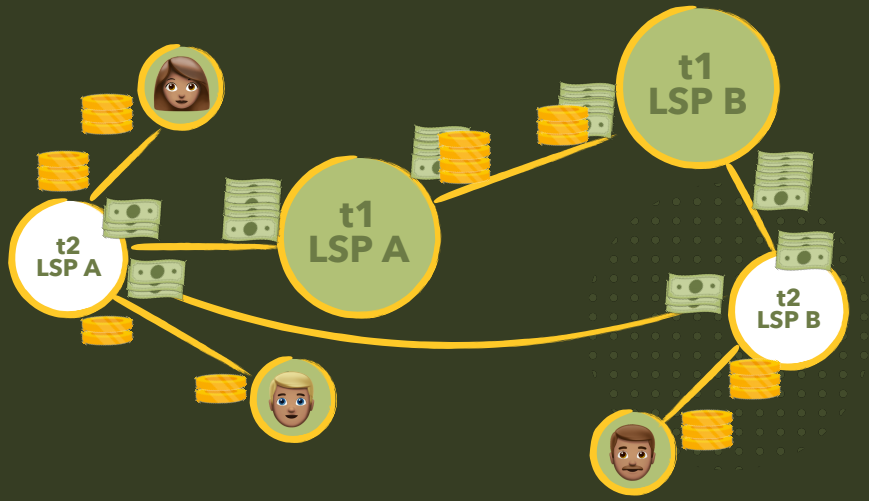
PROBLEM STATEMENT: THE TRADE-OFF
LOCKED LIQUIDITY – PAYMENT SUCCESS RATE

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**.

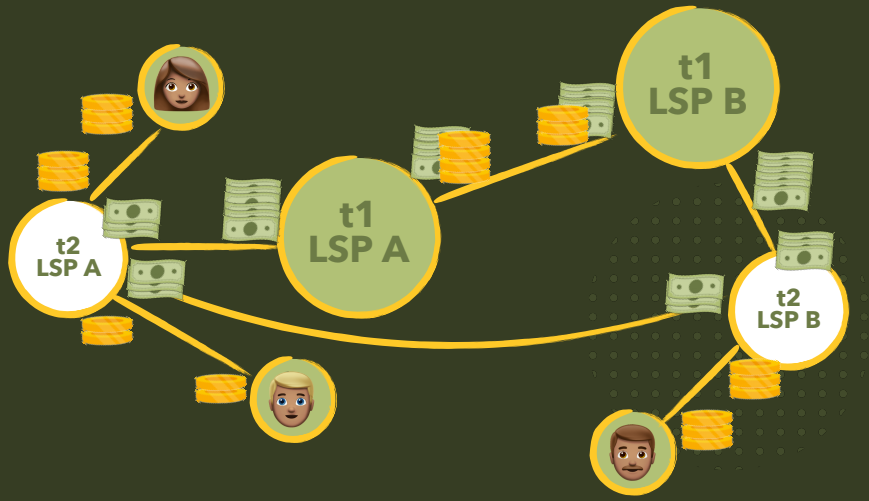


OUR IDEA
A PCN AS A DIGITAL PAYMENTS SYSTEM



OUR IDEA
A PCN AS A DIGITAL PAYMENTS SYSTEM

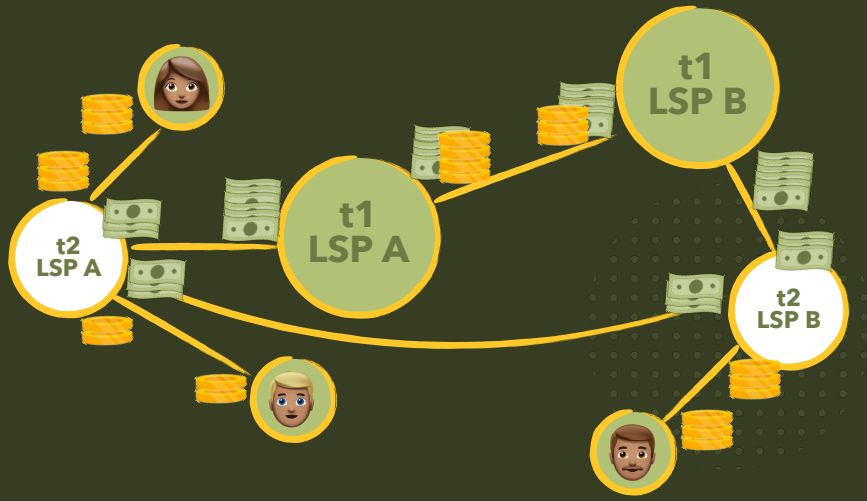
We envision a 2-tiers LSP topology:



OUR IDEA
A PCN AS A DIGITAL PAYMENTS SYSTEM

We envision a 2-tiers LSP topology:

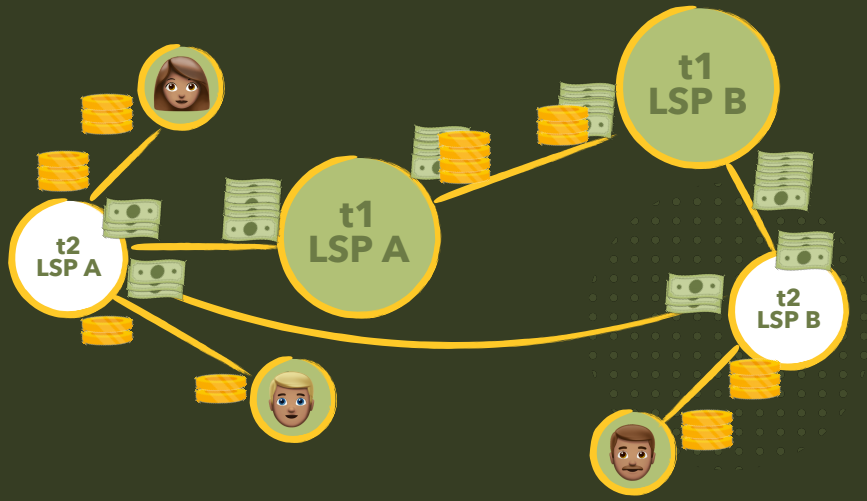
- **t1-LSP**: **provides liquidity** to tier-2 LSPs (e.g. Central Banks);



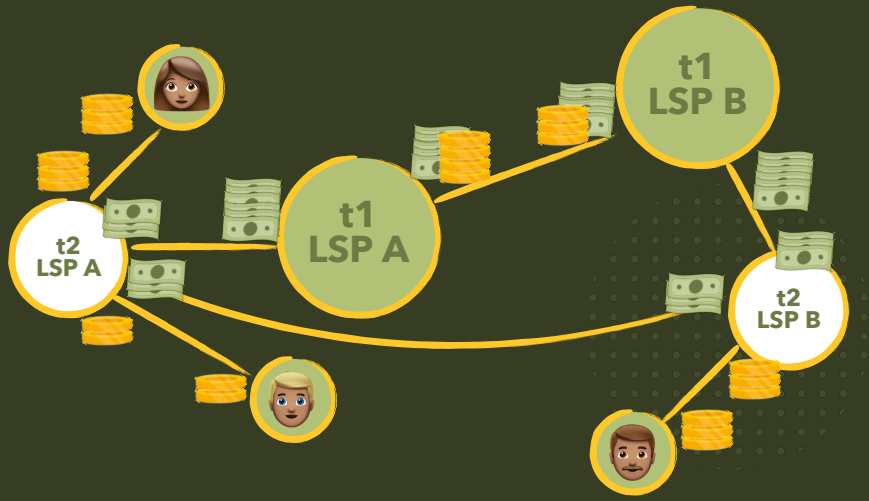
OUR IDEA
A PCN AS A DIGITAL PAYMENTS SYSTEM

We envision a 2-tiers LSP topology:

- **t1-LSP**: **provides liquidity** to tier-2 LSPs (e.g. Central Banks);
- **t2-LSP**: opens **channels** toward multiple **end-users** (e.g. Commercial Banks);

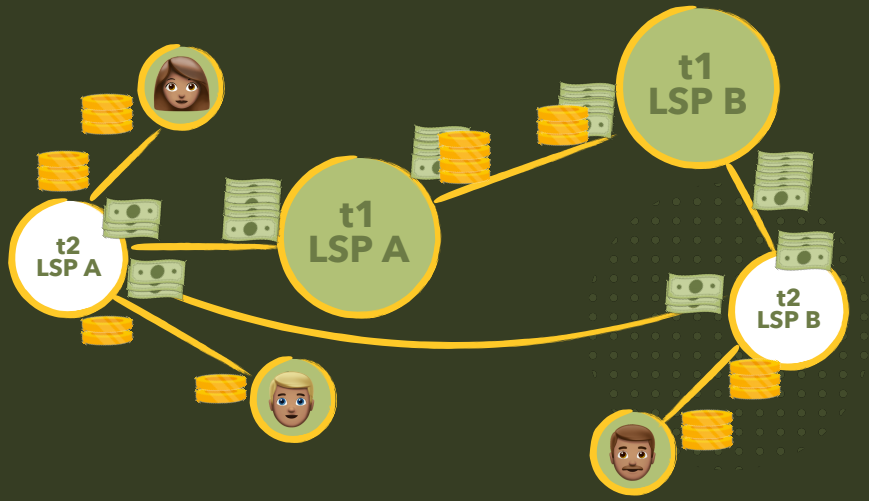


OUR IDEA
A PCN AS A DIGITAL PAYMENTS SYSTEM



OUR IDEA
A PCN AS A DIGITAL PAYMENTS SYSTEM

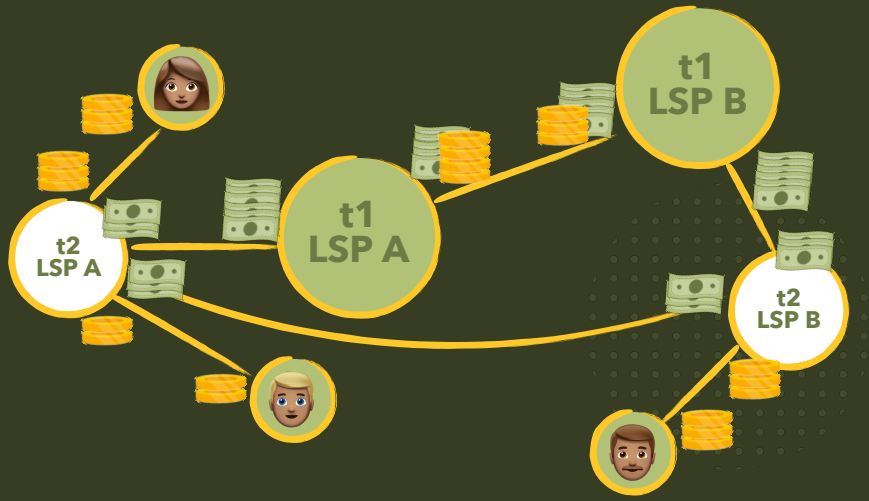
Advantages:



OUR IDEA
A PCN AS A DIGITAL PAYMENTS SYSTEM

Advantages:

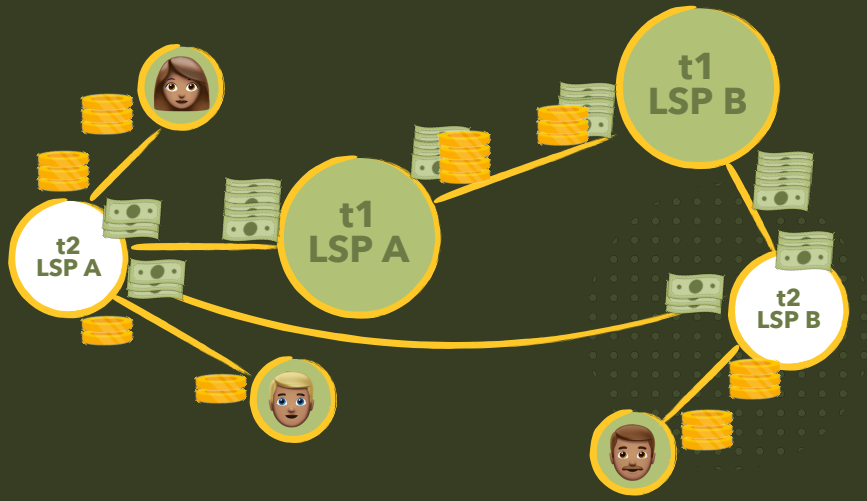
- Cryptographically-enforced **trust-less** payments



OUR IDEA
A PCN AS A DIGITAL PAYMENTS SYSTEM

Advantages:

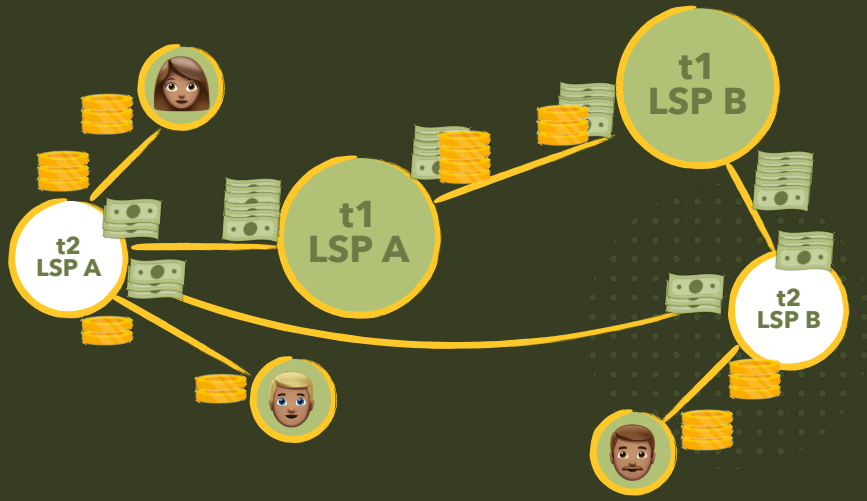
- Cryptographically-enforced **trust-less** payments
- **Reuse** existing protocols and applications (LN)



OUR IDEA
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.)



AGENDA

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

STUDYING PCNs NETWORK ASPECTS
THE CHALLENGES

STUDYING PCNs NETWORK ASPECTS
THE CHALLENGES

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

STUDYING PCNs NETWORK ASPECTS
THE CHALLENGES

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

- the lack of knowledge of **channel balances**;

STUDYING PCNs NETWORK ASPECTS
THE CHALLENGES

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**.

STUDYING PCNs NETWORK ASPECTS
THE CHALLENGES

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**.

Simulations used in many studies:

STUDYING PCNs NETWORK ASPECTS
THE CHALLENGES

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**.

Simulations used in many studies:

- *Lange et al.* [1] assumes **three** different transactions **volumes**;

STUDYING PCNs NETWORK ASPECTS
THE CHALLENGES

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**.

Simulations used in many studies:

- *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:

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

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**.

AGENDA

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**

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**?

RQ2.

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

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**?

RQ2.

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

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?

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?

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?

SYSTEM DESIGN
4 MAIN COMPONENTS

PCN TOPOLOGY GENERATOR

TXs GENERATOR

CALIBRATOR
Compute optimal channel capacities

PAYMENTS SIMULATOR

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.)

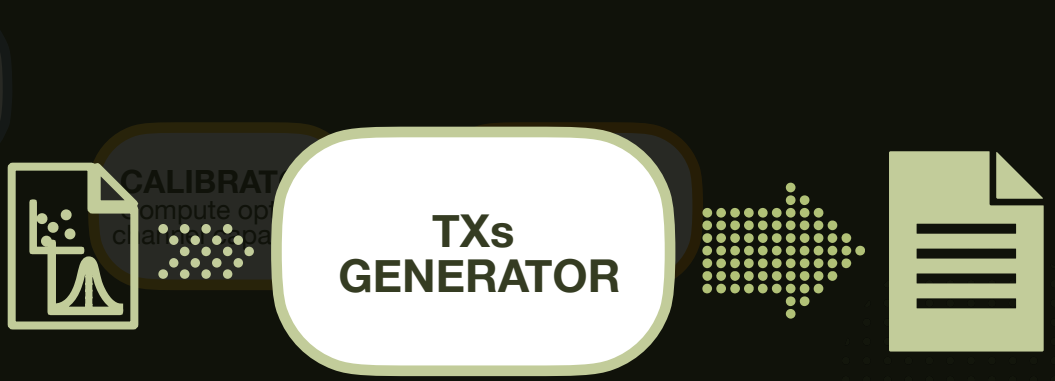
SYSTEM DESIGN

01. PCN TOPOLOGY GENERATOR

SYSTEM DESIGN
02. TRANSACTIONS GENERATOR

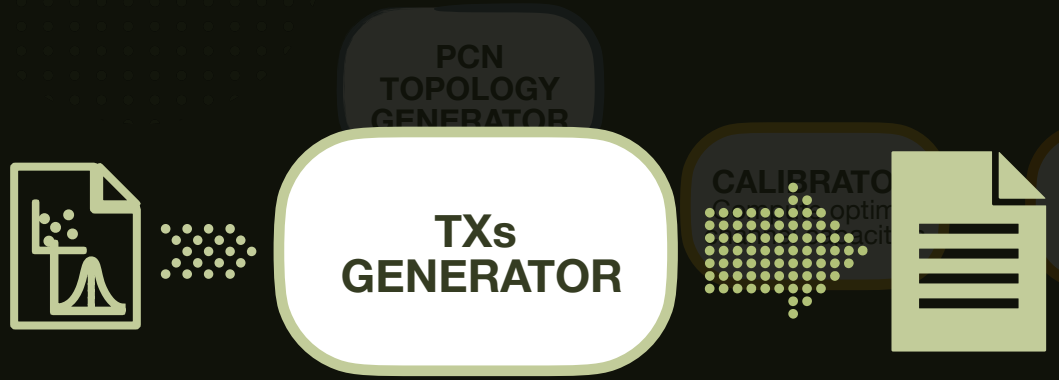
INPUT

- **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**



SYSTEM DESIGN

02. TRANSACTIONS GENERATOR



OUTPUT

Transactions file containing:

- **sender**
- **receiver**
- **tx type**
- **amount**
- **start time**

SYSTEM DESIGN

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**

PCN TOPOLOGY GENERATOR

TXs GENERATOR

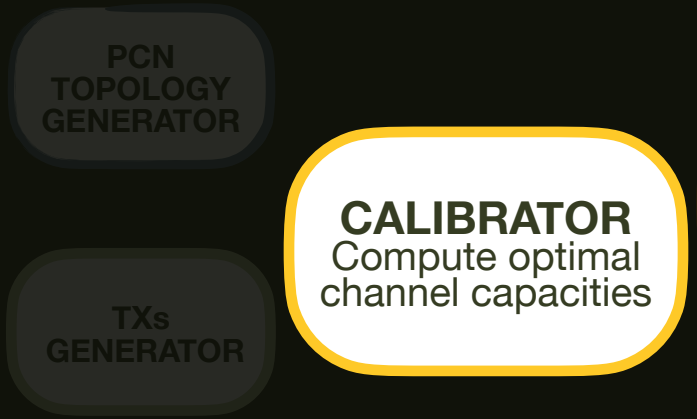
SYSTEM DESIGN

03. PAYMENTS SIMULATOR

OUTPUT

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

SYSTEM DESIGN
04. CALIBRATOR



GOAL

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

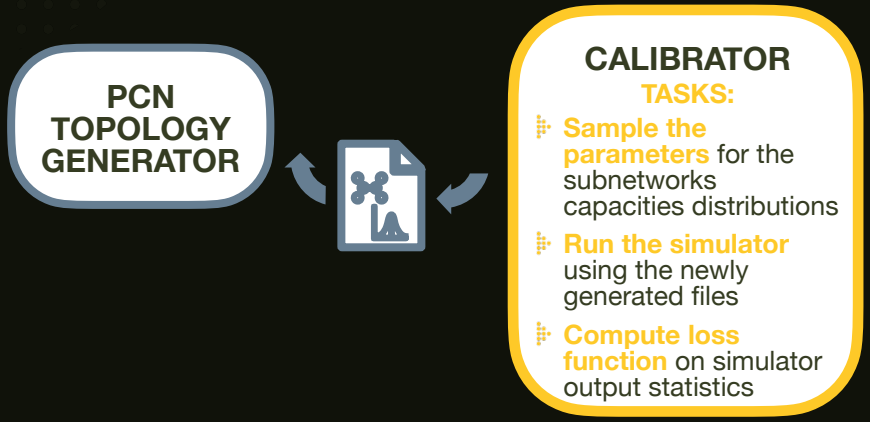
SYSTEM DESIGN
COMPONENTS INTERACTION

CALIBRATOR

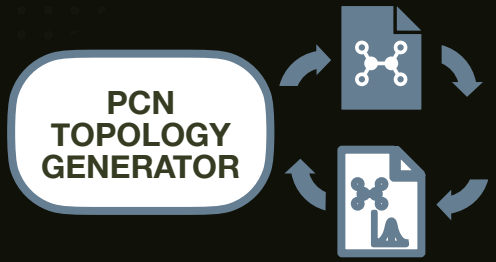
TASKS:

- **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



SYSTEM DESIGN
COMPONENTS INTERACTION

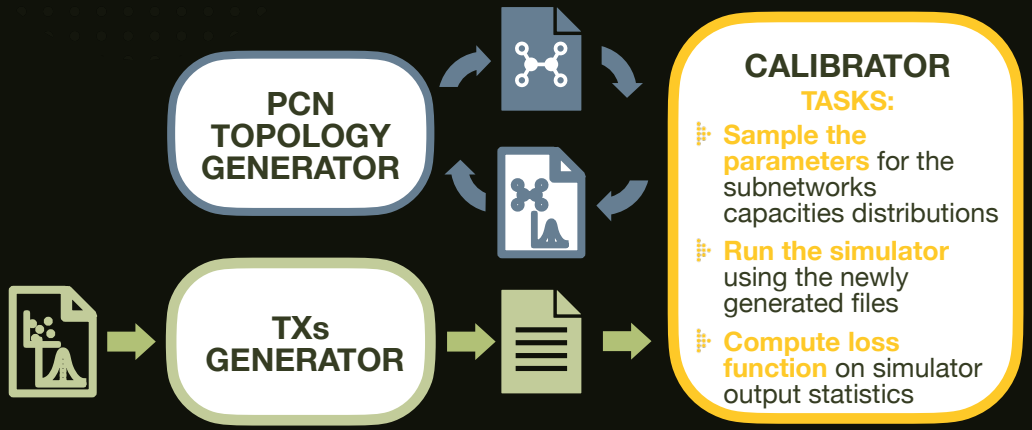


CALIBRATOR

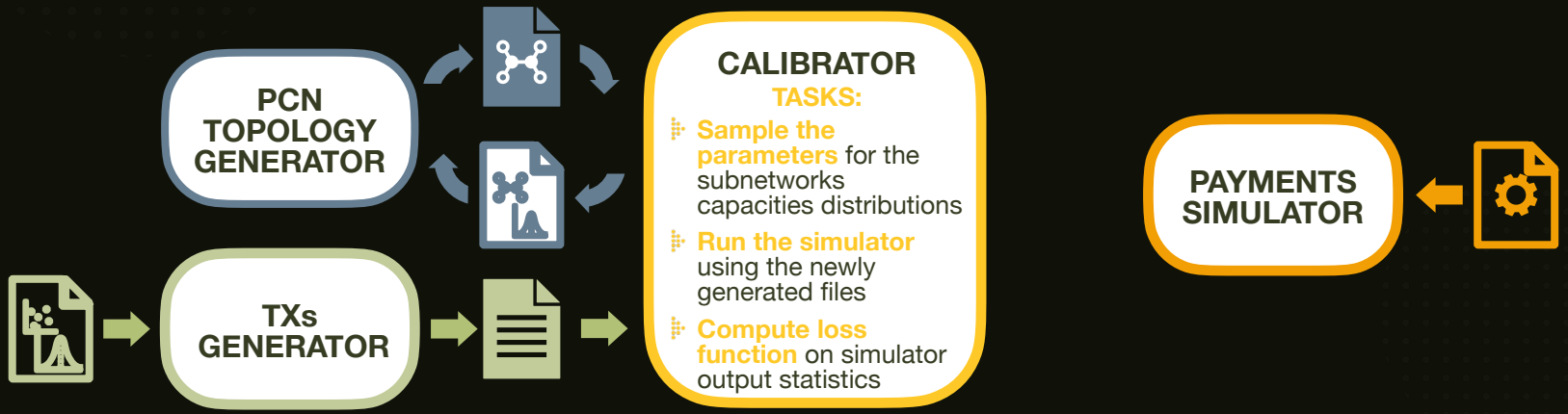
TASKS:

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

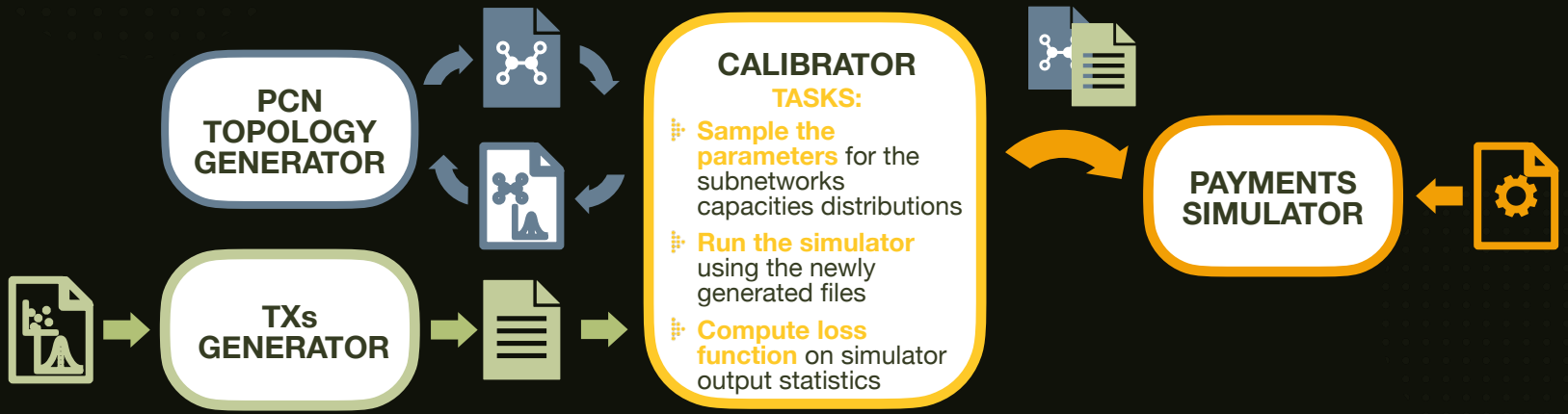
SYSTEM DESIGN
COMPONENTS INTERACTION



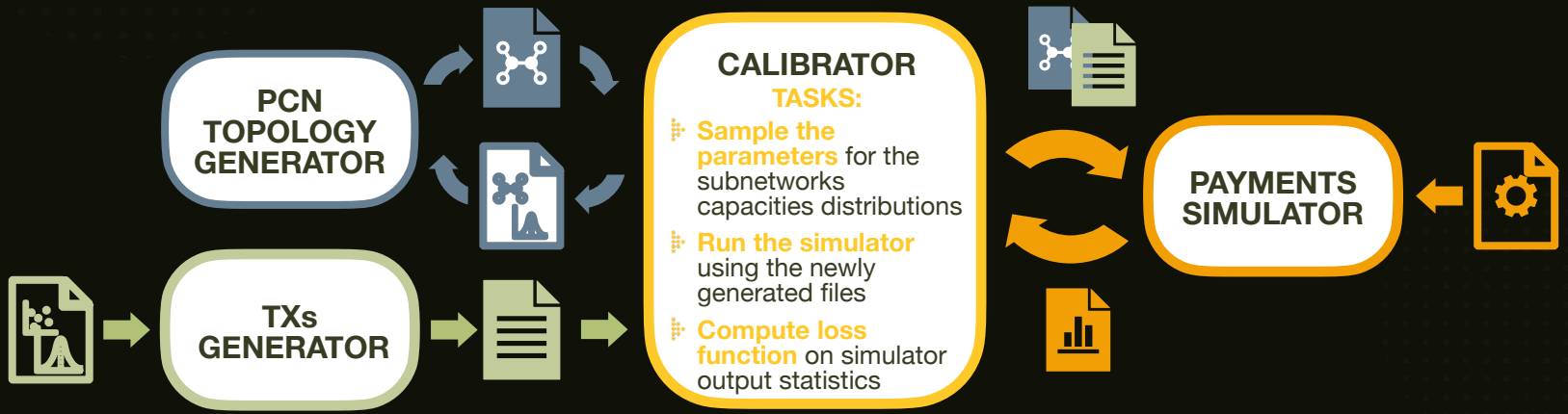
SYSTEM DESIGN
COMPONENTS INTERACTION



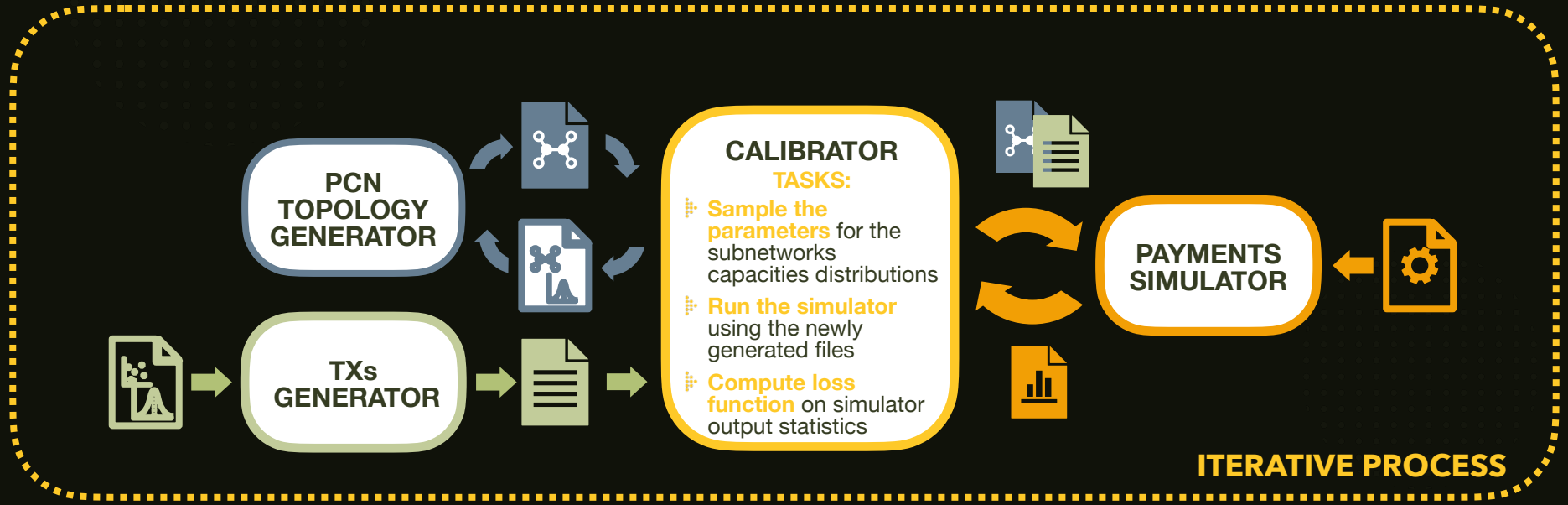
SYSTEM DESIGN
COMPONENTS INTERACTION



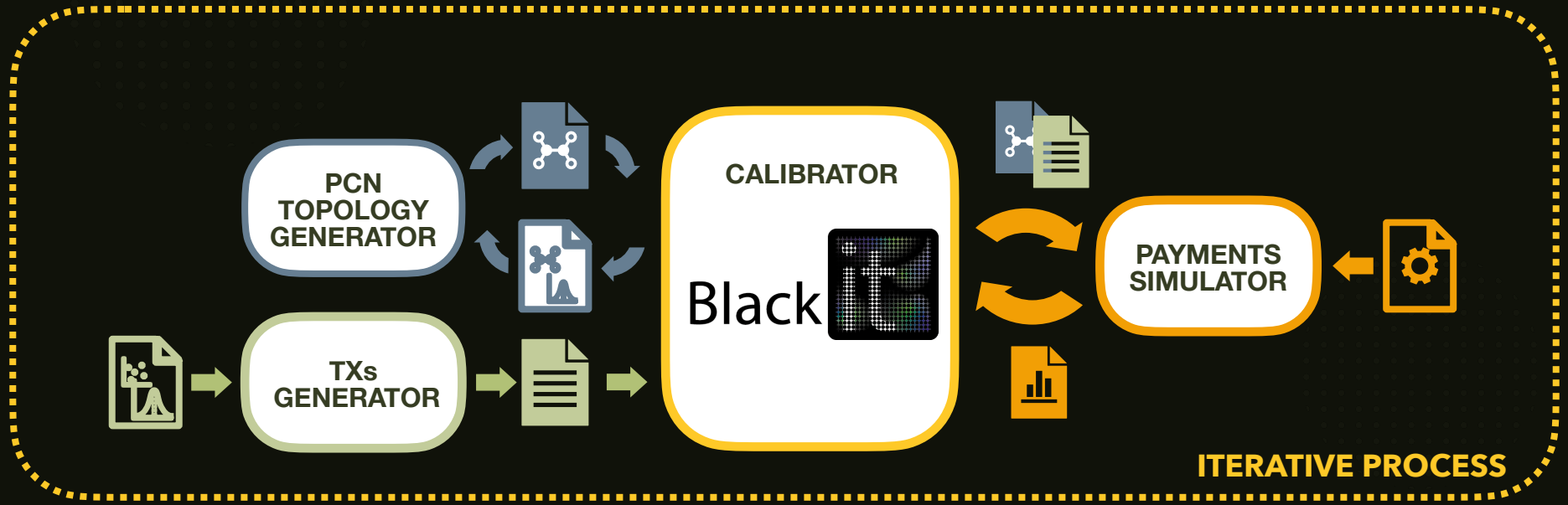
SYSTEM DESIGN
COMPONENTS INTERACTION



SYSTEM DESIGN
COMPONENTS INTERACTION



SYSTEM DESIGN
COMPONENTS INTERACTION



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?

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.

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

💡 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?

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**?

RQ2.

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

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?

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

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**?

RQ2.

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

RQ3.

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

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

RQ5.

What kind of **privacy challenges** would such an almost-fixed topology need to consider?

AGENDA

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

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 **possibile retail CBDC implementation**, where central banks and commercial banks could play the role of LSPs.

REFERENCES

(1) **On the Impact of Attachment Strategies for Payment Channel Networks.** *Kimberly Lange, Elias Rohrer, and Florian Tschorsch*. 2021. **2021 IEEE International Conference on Blockchain and Cryptocurrency (ICBC).** 1–9. DOI: http://dx.doi.org/10.1109/ICBC51069.2021.9461104

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

(3) **A Cryptoeconomic Traffic Analysis of Bitcoin's Lightning Network**. *Ferenc Beres, Istvan Andras Seres, and Andras A. Benczur*. 2019. DOI: http://dx.doi.org/10.48550/ARXIV.1911.09432

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

(5) **CLoTH: A Lightning Network Simulator.** *Marco Conoscenti, Antonio Vetrò, and Juan Carlos De Martin*.**Vol. 15. SoftwareX, 100717**. DOI: http://dx.doi.org/10.1016/j.softx.2021.100717

THANK YOU

QUESTIONS?

www.bankit.art