GT DRONECHAIN-UTM

André Elias Melo, **Rafael Hickmann Albarello**,

Rodrigo Sérgio dos Santos Nunes, **Lourenço Alves Pereira Júnior**

RNP

ITA

PROJETO iliadA

Blockchain em evolução.

SUMÁRIO

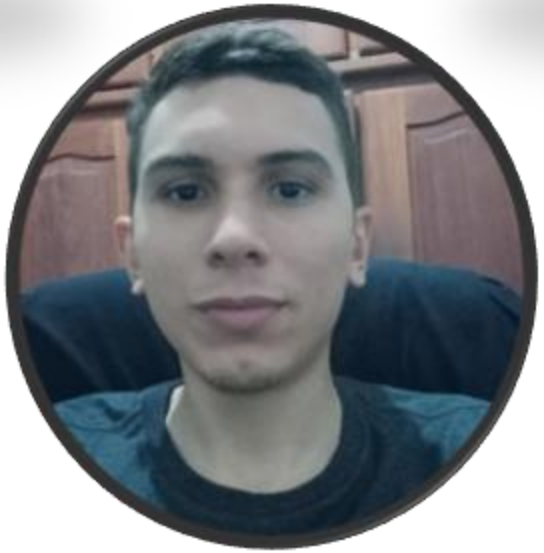
ITS aéreo como novo vertical

Blockchain como backend

Avaliação de desempenho

Implementação em Besu

Considerações finais



AI
AI

EVE

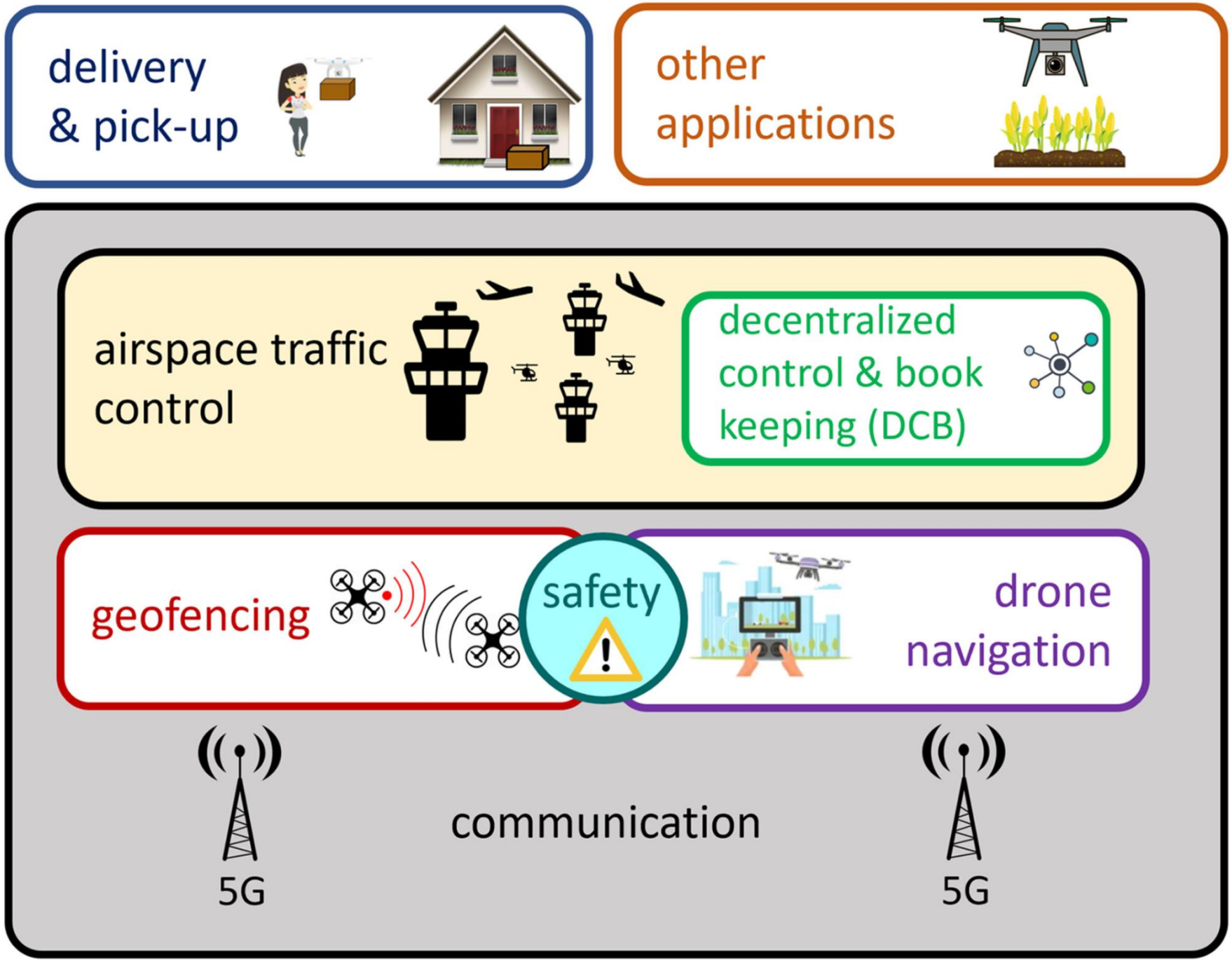
EM RESUMO

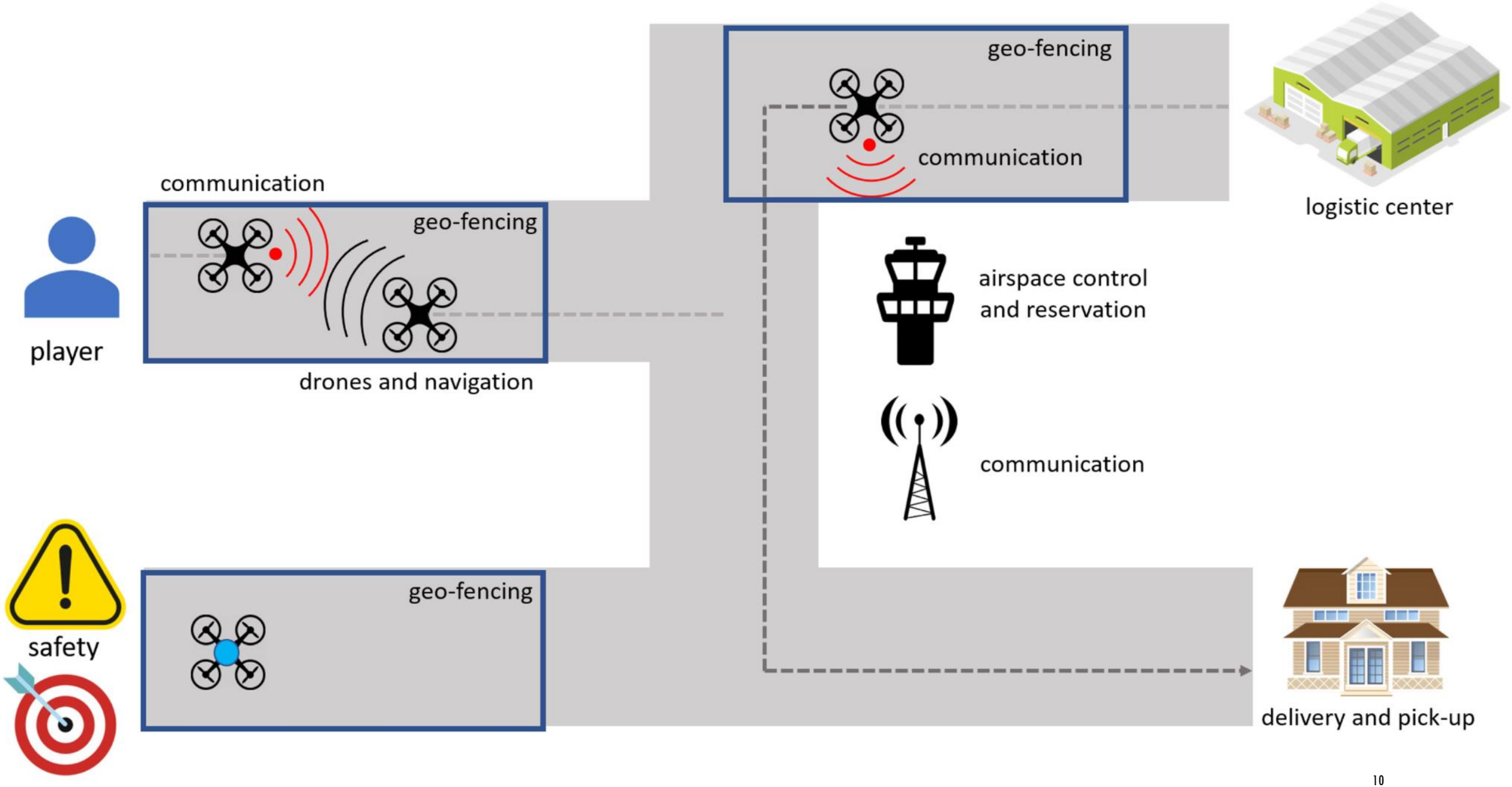
Avanços de IA

Sistemas de Transportes Inteligentes

Tecnologias habilitadoras para novos verticais

mas como esses sistemas são?


delivery
& pick-up
other
applications
airspace traffic
control
decentralized
control & book
keeping (DCB)
geofencing
safety
drone
navigation
communication
5G
5G


geo-fencing
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geo-fencing
player
drones and navigation
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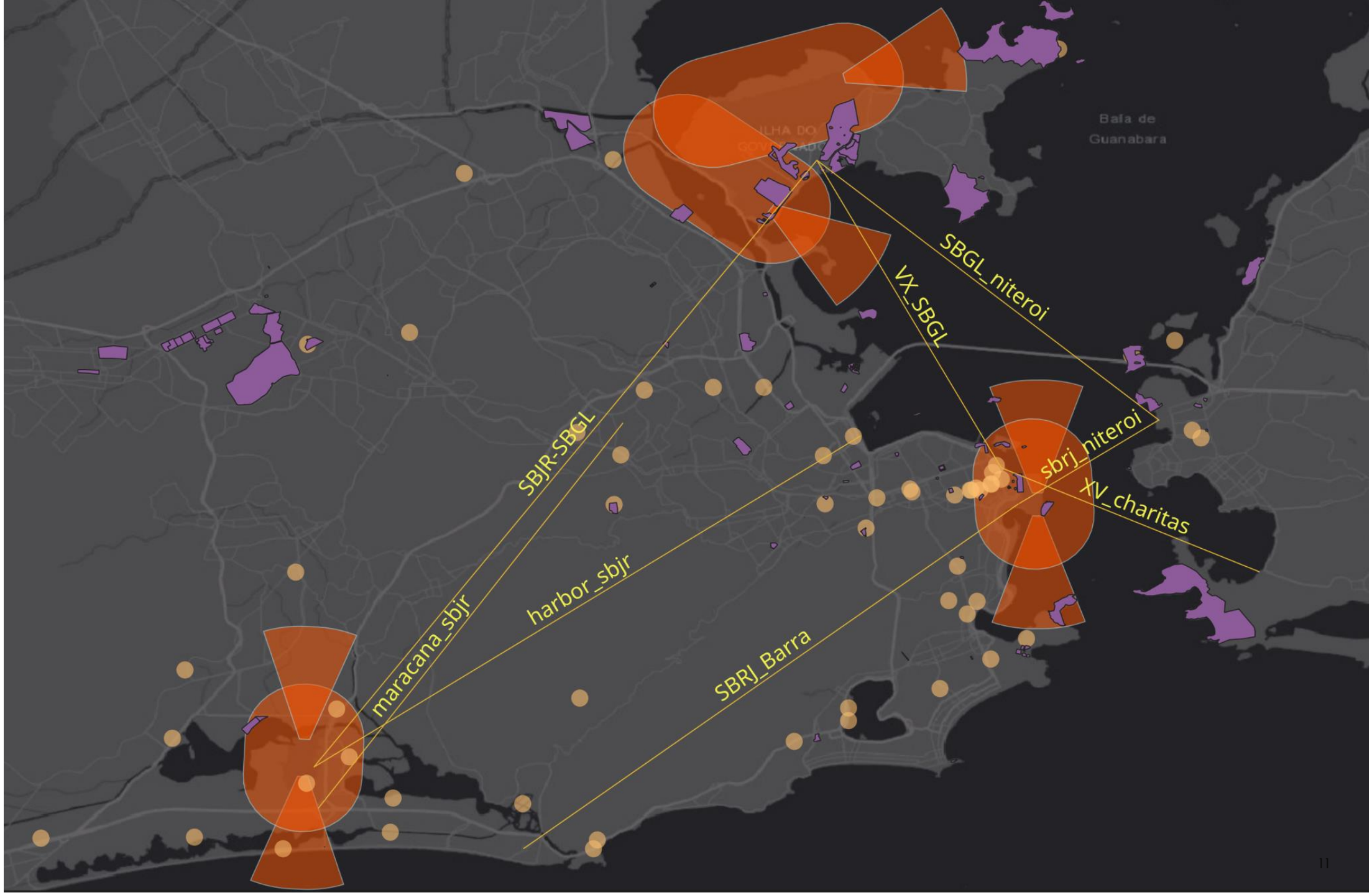
and reservation
communication
safety
geo-fencing
delivery and pick-up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XV_charitas
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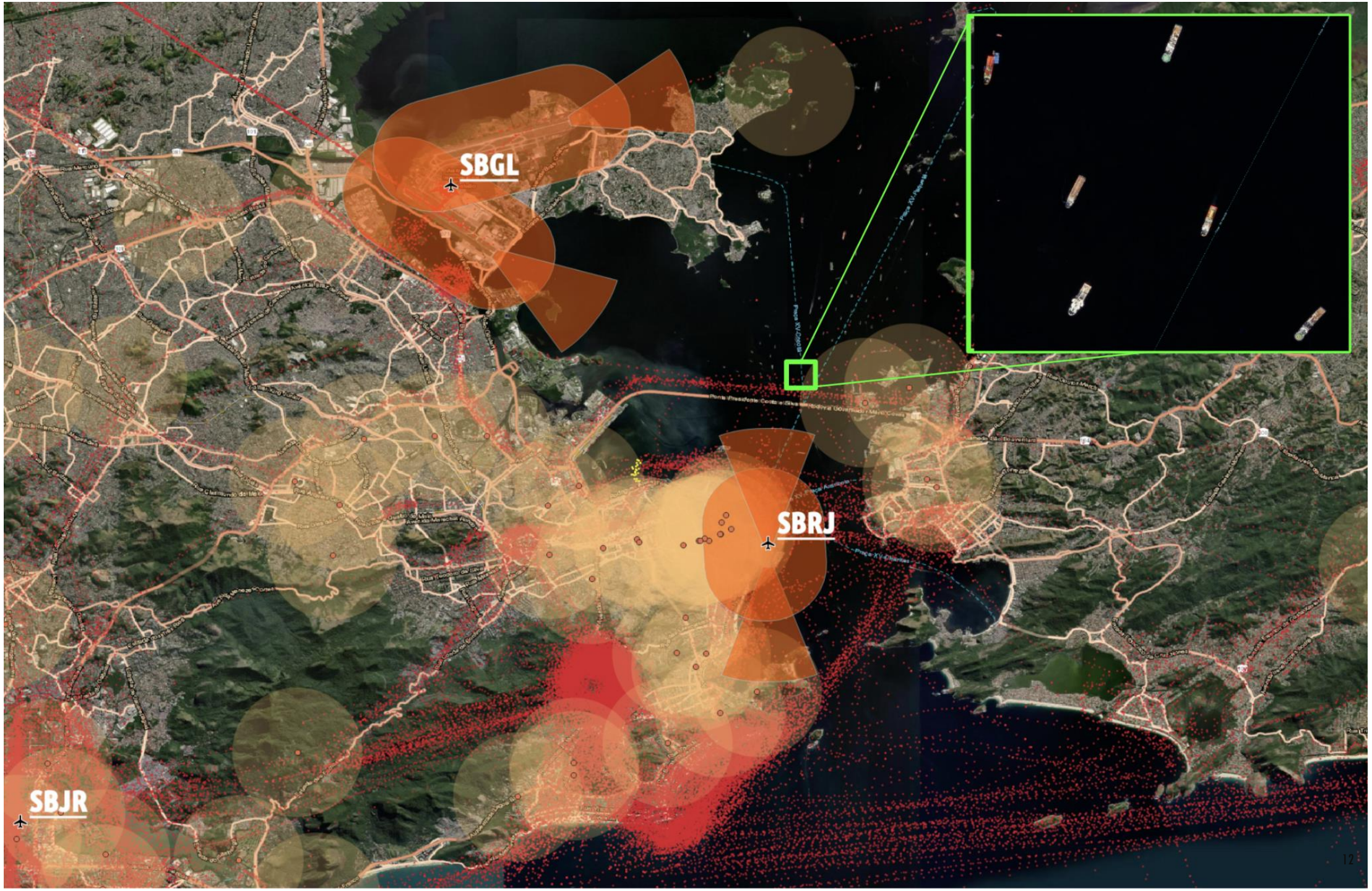
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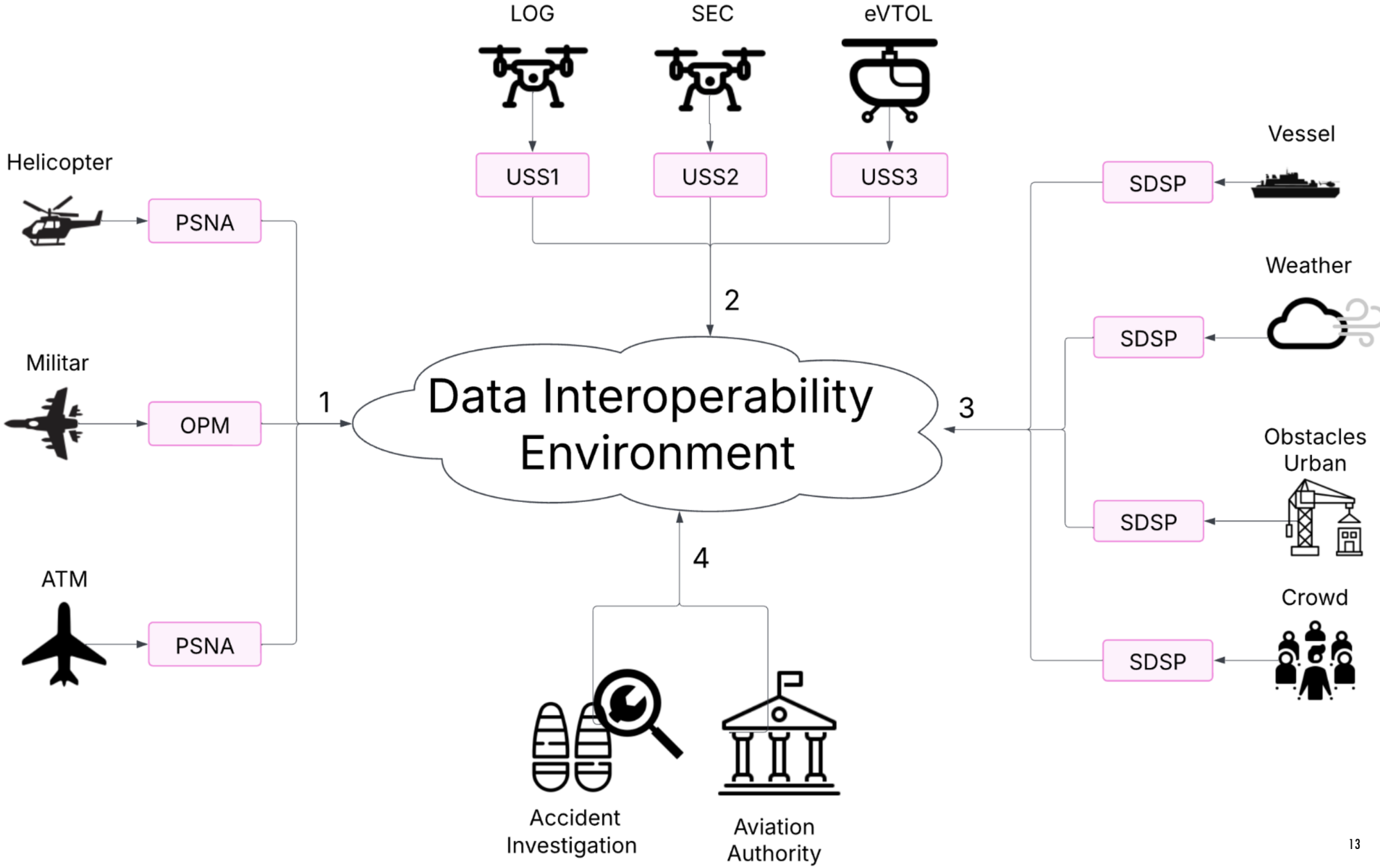
SBJR


LOG
SEC
eVTOL
USS1
USS2
USS3
Helicopter
PSNA
Militar
OPM
ATM
PSNA
1
2
3
4
Data Interoperability Environment
Vessel
SDSP
Weather
SDSP
Obstacles Urban
SDSP
Crowd
SDSP
Accident Investigation
Aviation Authority

THE LINUX FOUNDATION PROJECTS

InterUSS Platform

ABOUT PROJECTS UTM / U-SPACE DEPLOYMENTS DEVELOPER RESOURCES NEWSROOM JOIN

The InterUSS Project seeks to advance uncrewed aviation through industry collaboration, open standards, and interoperability among all uncrewed aircraft.

BECOME A MEMBER

JOIN THE ADVISORY COUNCIL

OBJETIVOS

- Avaliar aplicabilidade de blockchain no gerenciamento do tráfego aéreo não tripulado brasileiro
  - Adaptar backend para blockchain
- Comparar desempenho das plataformas blockchain para a oportunidade selecionada
  - InterUSS vs Fabric
- Desenvolver contrato inteligente compatível com as especificações de UTM
  - Desenvolvimento Besu from scratch

GERENCIAMENTO DE TRÁFEGO AÉREO NÃO TRIPULADO - UTM

- Gerenciamento do tráfego de drones eficiente e seguro
- Integração de tecnologias (conectividade, automação e coordenação)
- Descentralizado por natureza
- Pesquisa feita em parceria com o ICEA + BR-UTM

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PRIMEIRO OBJETIVO: INTERUSS AS IS

- InterUSS - DSS
- Implementação em Golang
- Descentralização via CockroachDB
- Serviço core do UTM, especificado na ASTM F3548-21

InterUSS
Platform

THE LINUX FOUNDATION

ASTM F3548-21

Standard Specification for UAS Traffic Management (UTM) UAS Service Supplier (USS) Interoperability

PRIMEIRO CONTRATO INTELIGENTE: AS-IS

- Hyperledger Fabric
- Mesma implementação de geoindexação do InterUSS
- Implementado com cctools da goledger
- Objetivo de comparação de desempenho, mantido apenas as funcionalidades existentes no InterUSS

```go
Routine: func(stub *sw.StubWrapper, req map[string]interface{}) ([]byte, errors.ICCError) {
	paramJson, err := json.Marshal(req)
	if err != nil {
		return nil, errors.WrapErrorWithStatus(err, "failed to marshal req", 400)
	}
	var param datatypes.PutOperationalIntentReferenceParameters
	err = json.Unmarshal(paramJson, &param)
	if err != nil {
		return nil, errors.WrapErrorWithStatus(err, "failed to unmarshal req", 400)
	}

	oirMap := make(map[string]interface{})
	oirMap["@assetType"] = "operational_intent_reference"
	oirMap["id"] = stub.Stub.GetTxID()
	managerBytes, err := stub.Stub.GetCreator()
	if err != nil {
		return nil, errors.WrapErrorWithStatus(err, "failed to get creator", 400)
	}
	oirMap["manager"] = string(managerBytes)
	oirMap["state"] = string(param.State)
```

https://git.rnp.br/iliada-blockchain/gts/gt-dronechain-utm/dronechain-interuss/-/blob/main/dronechain-interuss-as-is/chaincode/txdefs/createOperationalIntentReference.go?ref_type=heads#L39

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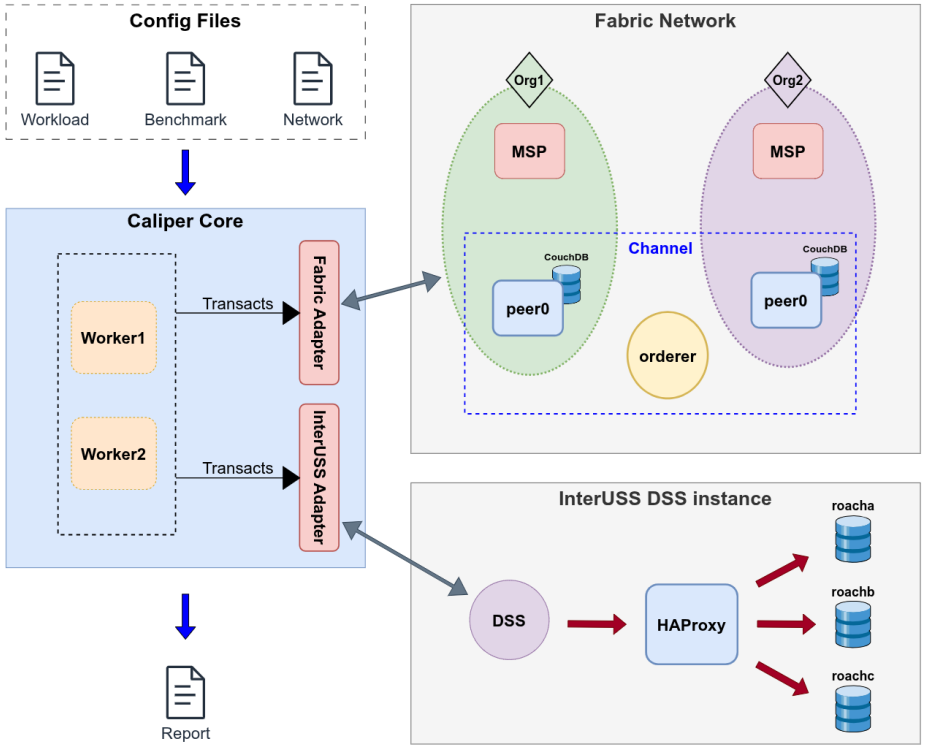
BENCHMARK: INTERUSS VS FABRIC

- Benchmark feito via Hyperledger Caliper
- Rede Local (test-network)
- Ambos SUT sob exatamente a mesma carga de trabalho
- Cargas variáveis de 50, 500 e 5000 transações entre 5 e 20 TPS



HYPERLEDGER CALYPER HTTP CONNECTOR

- NodeJS
- Autentica no DSS antes da carga de trabalho
- Converte o workload para JSON
- Request ao DSS utilizando axios

```
async _sendSingleRequest(request) {
    if (request.contractFunction == 'queryOperationalIntentReference') {
        return await this._readOperationalIntent(request, this.token)
    }

    if (request.contractFunction == 'createOperationalIntentReference') {
        return await this._createOperationalIntent(request, this.token)
    }
    logger.error(`Contract function ${request.contractFunction} not implemented`)
    throw new Error(`Contract function ${request.contractFunction} not implemented`)

}
```

https://git.rnp.br/iliada-blockchain/gts/gt-dronechain-utm/dronechain-interuss/-/blob/main/caliper-workspace/caliper-http/lib/HttpConnector.js?ref_type=heads#L36

PRIMEIRO BENCHMARK

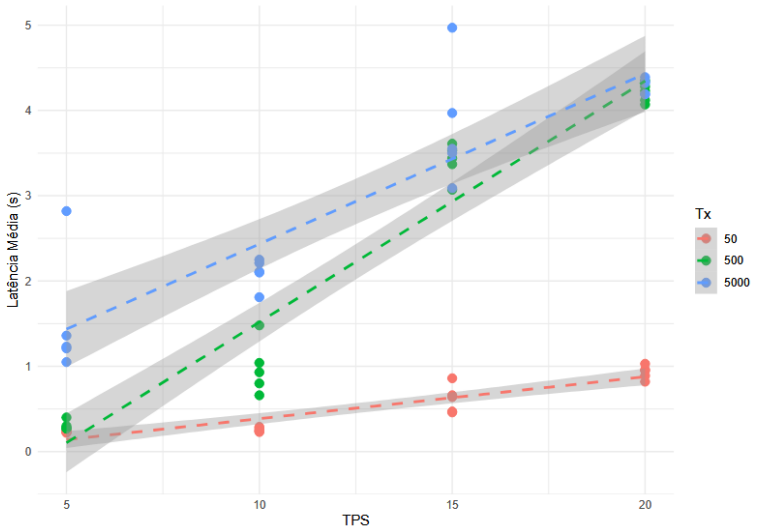


Figura 5. Latência Média por TPS com Tendências (Create OpIntent) no InterUSS.

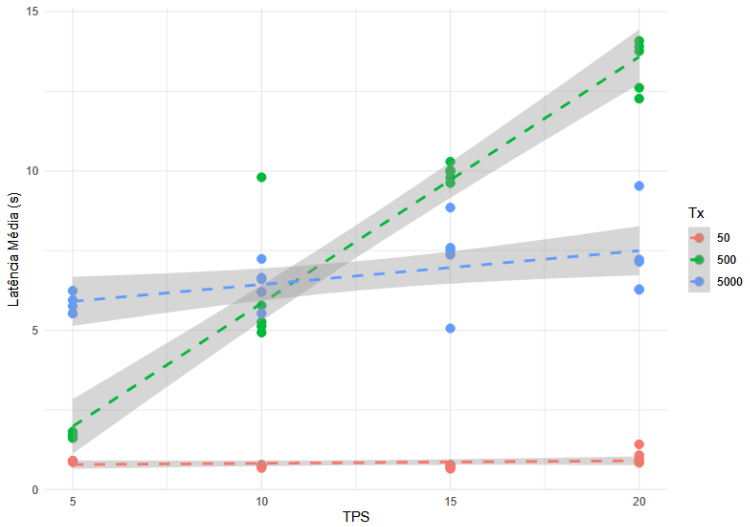


Figura 7. Latência Média por TPS com Tendências (Create OpIntent) na Blockchain.

NUNES, Rodrigo Sergio dos Santos; MELO, Andre Elias; ALBARELLO, Rafael Hickman; GOMES, Reinaldo Cezar de Morais; MARCONDES, Cesar; PEREIRA JUNIOR, Lourenço Alves. **Benchmarking de Performance de Sistemas Distribuídos Aplicados à Mobilidade Aérea Urbana**. In: WORKSHOP DE COMPUTAÇÃO URBANA (COURB), 9. , 2025, Natal/RN. Anais [...]. Porto Alegre: Sociedade Brasileira de Computação, 2025 . p. 321-334. ISSN 2595-2706. DOI: https://doi.org/10.5753/courb.2025.9594.

PRIMEIRO BENCHMARK

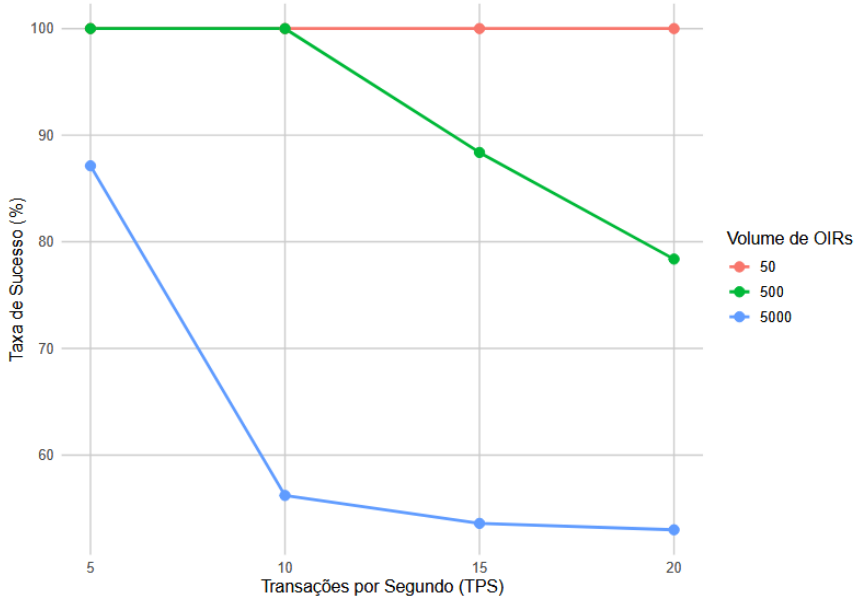


Figura 6. Taxa de Sucesso por TPS e Volume de OIRs no InterUSS.

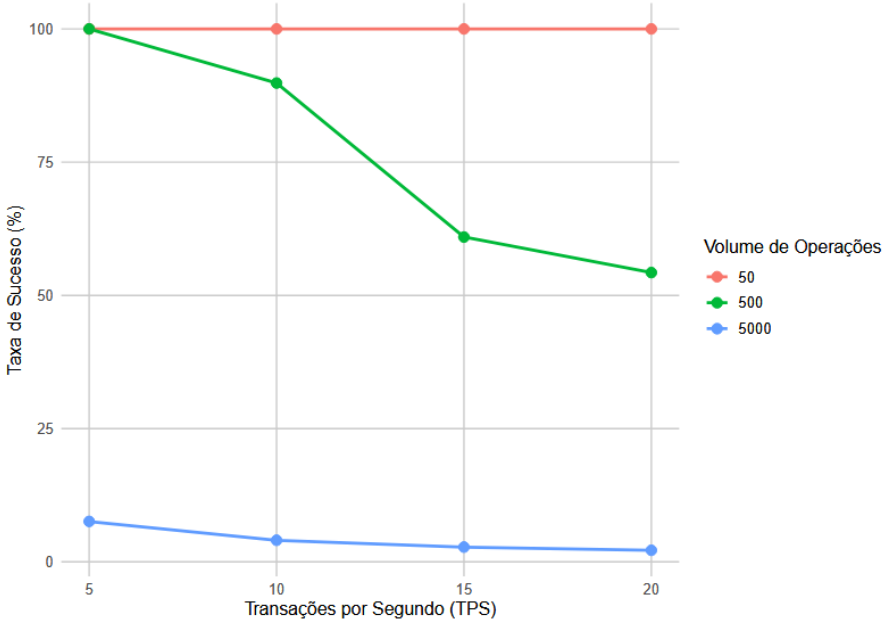
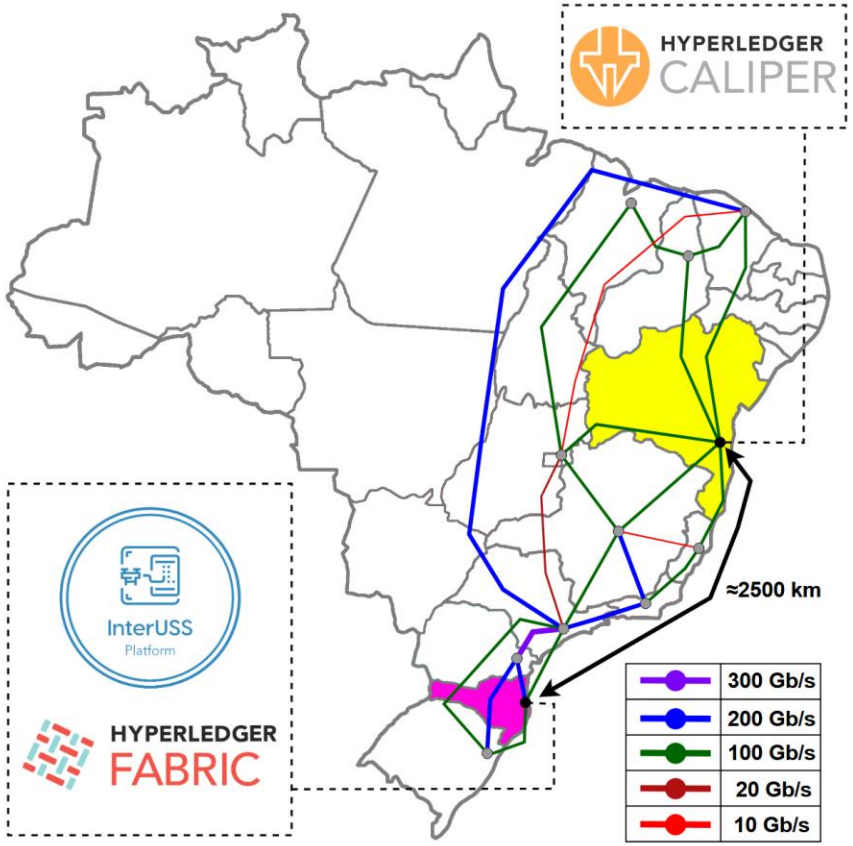


Figura 8. Taxa de Sucesso por TPS e Volume de OIRs na Blockchain.

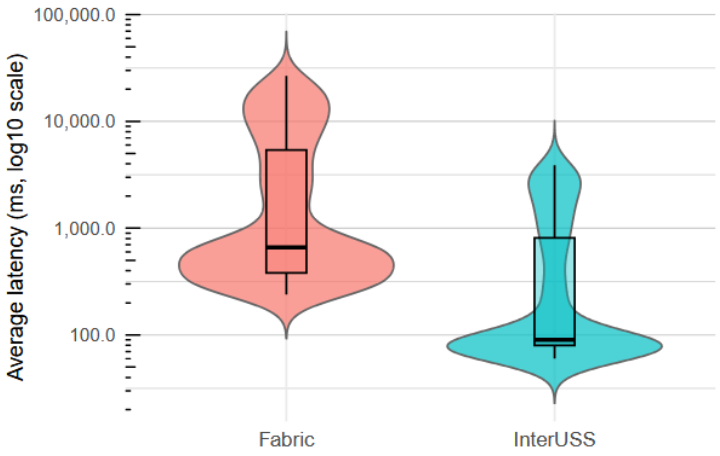
NUNES, Rodrigo Sergio dos Santos; MELO, Andre Elias; ALBARELLO, Rafael Hickman; GOMES, Reinaldo Cezar de Morais; MARCONDES, Cesar; PEREIRA JUNIOR, Lourenço Alves. **Benchmarking de Performance de Sistemas Distribuídos Aplicados à Mobilidade Aérea Urbana**. In: WORKSHOP DE COMPUTAÇÃO URBANA (COURB), 9. , 2025, Natal/RN. Anais [...]. Porto Alegre: Sociedade Brasileira de Computação, 2025 . p. 321-334. ISSN 2595-2706. DOI: https://doi.org/10.5753/courb.2025.9594.

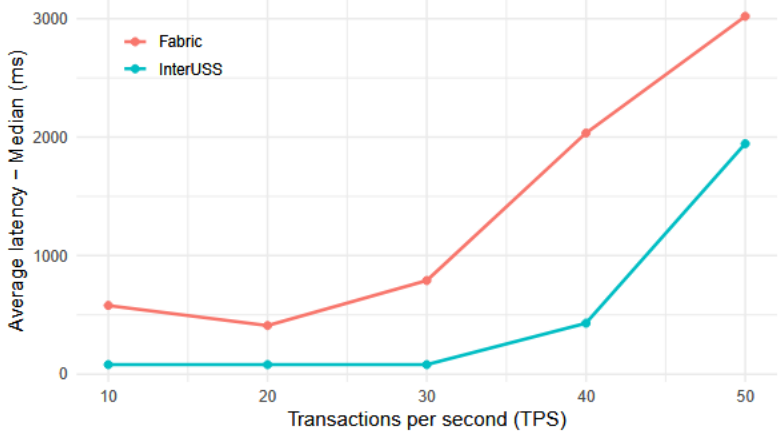
DESEMPENHO EM AMBIENTE DISTRIBUÍDO

- Maior volume de execução dos testes
- Utilizando a rede RNP-ilíada
- SUT geograficamente distribuído do Worker
- 100 a 2000 transações totais (incrementos de 100)
- 10 a 50 TPS (incrementos de 10)

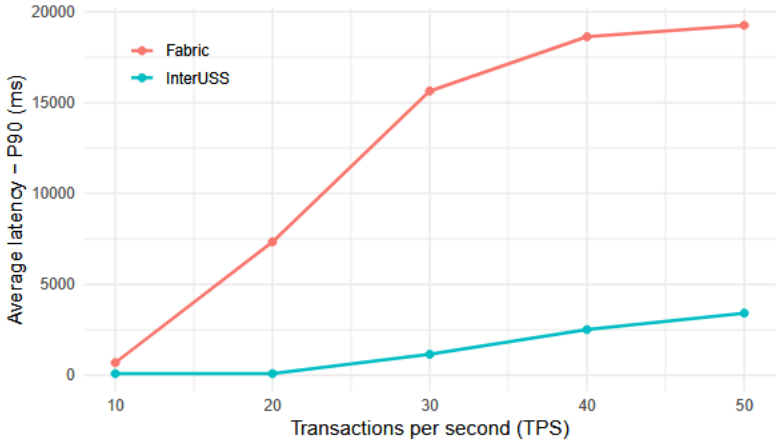


RESULTADOS EM AMBIENTE DISTRIBUÍDO

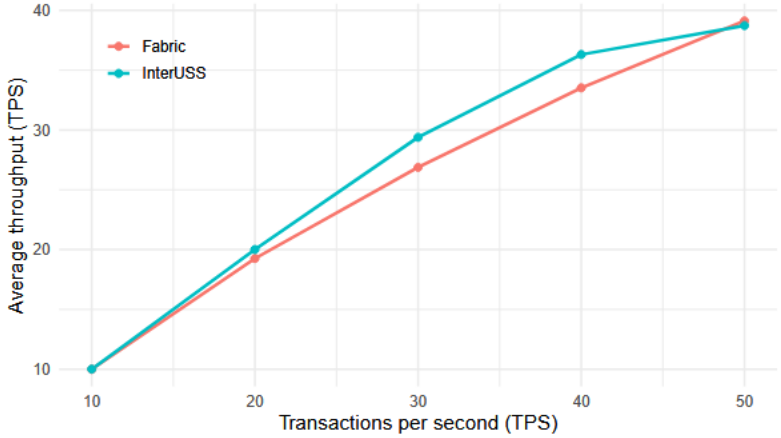




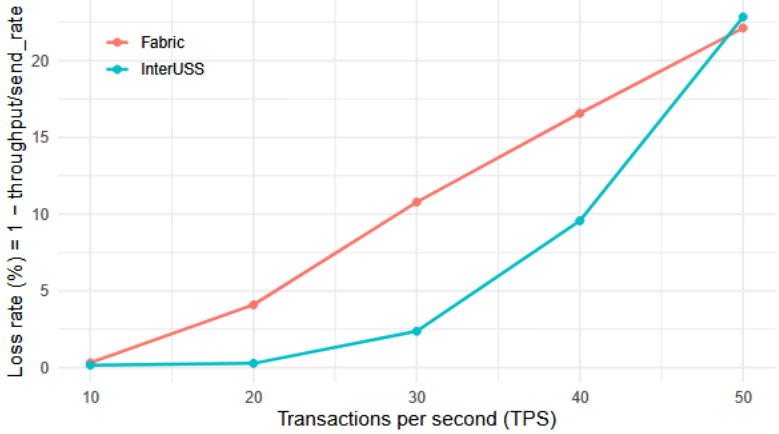
(a) Median latency (p50)



(b) P90 latency



(c) Throughput



(d) Loss rate

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CONTRATO BESU: DRONECHAIN

- **Gestão de *Operational Intent***
- **Reserva de Espaço Aéreo em NFT**
- **Identidade e Controle de Acesso**
- **Otimização de Busca**
- **Emissão de Eventos**
- **Arquitetura em camadas**

CONTRATO DRONECHAIN

- Mudança de Fabric para Besu (Solidity)
  - Maior comunidade
  - Facil integração com ferramentas como Truffle, Hardhat e Ganache
  - Portal RNP com capacidade de rede distribuída Besu
- Arquitetura em Layers
  - Layer0: Base da reserva de espaço aéreo
  - Layer1: Geo-indexação
  - Layer2: Aplicação (Operational Intent, Constraints, Obstacle data, etc)

```
contract AirspaceLayer0 is ERC1155, AccessControl, ReentrancyGuard {
    using AirspaceTypes for AirspaceTypes.Volume4D;

    bytes32 public constant USS_ROLE = keccak256("USS_ROLE");
    bytes32 public constant AUTHORITY_ROLE = keccak256("AUTHORITY_ROLE");

    uint256 private _currentTokenId;
    uint256 private _currentRequestId;

    // Token ID => Volume4D mapping
    mapping(uint256 => AirspaceTypes.Volume4D) public airspaceVolumes;

    // Geohash => AirspaceReservation[] (sorted by startTime for efficient searching)
    mapping(string => AirspaceTypes.AirspaceReservation[]) public geohashReservations;

    // Request ID => Authorization Request
    mapping(uint256 => AirspaceTypes.AirspaceRequest) public authorizationRequests;

    // Token ID => Array of pending request IDs
    mapping(uint256 => uint256[]) public tokenPendingRequests;
```

https://git.rnp.br/iliada-blockchain/gts/gt-dronechain-utm/dronechain-nft/-/blob/master/contracts/AirspaceLayer0.sol?ref_type=heads#L9

CONSIDERAÇÕES FINAIS

PRÓS - CONTRAS

- Integridade e Segurança dos dados
- Auditabilidade
- Resiliência à falhas
- Automação por Smart Contracts
- Tokenização do Espaço Aéreo

- Latência
- Maior complexidade e curva de onboarding
- Maturidade dos frameworks permissionados

DESAFIOS E TRABALHOS FUTUROS

- Criação da rede geograficamente distribuída
- Implantação do contrato Solidity ERC1155 em Besu
- Hyperledger Caliper descontinuando suporte à Besu
- Otimização do contrato inteligente e integração com dApps e API UTM

CONCLUSÃO

Valor da pesquisa evidente em ITS aéreo

Avaliação de Desepenho de Blockchain como backend

Implementação em Besu

Contribuições:

https://git.rnp.br/iliada-blockchain/gts/gt-dronechain-utm/

- 1 SBRC – Trilha Industrial
- 1 CoUrb Workshop
- 1 Submissão no IEEE ICC 2026

SkyLedger: *Testbed* para o Gerenciamento do Espaço Aéreo para Sistemas de Transportes Inteligentes

Andre Elias Melo [1], Rafael Hickmann Albarello[1], Rodrigo Sergio dos Santos Nunes [1], Reinaldo Cezar de Morais Gomes [2], Cesar Marcondes e Lourenço Alves Pereira Junior[1]

[1]Divisão de Ciência da Computação – ITA – São Jose dos Campos, SP – Brazil

[2]Rede Nacional de Pesquisas – RNP – Rio de Janeiro, RJ – Brazil

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reinaldo.gomes@rnp.br,{cmarcondes,ljr}@ita.br

Abstract. *The versatility of drones, combined with their low infrastructure requirements for operation, has driven expectations of a sharp increase in airspace demand. In this context, the evolution of air traffic management models becomes essential to support this growing demand while ensuring safety, efficiency, and scalability for Advanced Air Mobility (AAM). This work presents requirements, challenges, and opportunities for a testbed based on permissioned Distributed Ledger Technologies (DLT) to enable data interoperability in AAM environments in compliance with Brazilian regulatory frameworks.*

MELO, Andre Elias; ALBARELLO, Rafael Hickmann; DOS SANTOS NUNES, Rodrigo Sergio; DE MORAIS GOMES, Reinaldo Cezar; MARCONDES, Cesar; PEREIRA JÚNIOR, Lourenço Alves. **SkyLedger: Test Bed para o Gerenciamento do Espaço Aéreo para Sistemas de Transportes Inteligentes.** In: TRILHA DE INOVAÇÃO E INTERAÇÃO COM A INDÚSTRIA - SIMPÓSIO BRASILEIRO DE REDES DE COMPUTADORES E SISTEMAS DISTRIBUÍDOS (SBRC), 43. , 2025, Natal/RN. Anais [...]. Porto Alegre: Sociedade Brasileira de Computação, 2025 . p. 388-393

Benchmarking de Performance de Sistemas Distribuídos Aplicados à Mobilidade Aérea Urbana

Rodrigo Sergio dos Santos Nunes [1], Andre Elias Melo [1], Rafael Hickmann Albarello[1], Reinaldo Cezar de Morais Gomes [2], Cesar Marcondes e Lourenço Alves Pereira Junior[1]

[1]Divisão de Ciência da Computação – ITA – São Jose dos Campos, SP – Brazil

[2]Rede Nacional de Pesquisas – RNP – Rio de Janeiro, RJ – Brazil

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reinaldo.gomes@rnp.br,{cmarcondes,ljr}@ita.br

Abstract. *Urban Air Mobility (UAM) aims to revolutionize metropolitan transportation by enabling low-altitude air traffic networks that provide flexible and rapid aerial services through the use of drones and eVTOLs. However, integrating these new airspace users into already saturated urban airspace, often constrained by both commercial aviation and dynamic ground-level obstacles, presents substantial challenges. To ensure safety and maintain operational standards, there is an increasing need for well-structured frameworks that support airspace planning and system interoperability. Emerging operational concepts propose a distributed architecture in which multiple service providers manage access and share information about airspace constraints and conditions. However, deploying distributed systems in safety-critical contexts introduces various overheads, particularly in terms of system performance. Based on future projections of airspace access demand, our findings indicate that current state-of-the-art solutions may not meet the scalability requirements of future UAM systems.*

NUNES, Rodrigo Sergio dos Santos; MELO, Andre Elias; ALBARELLO, Rafael Hickman; GOMES, Reinaldo Cezar de Morais; MARCONDES, Cesar; PEREIRA JUNIOR, Lourenço Alves. **Benchmarking de Performance de Sistemas Distribuídos Aplicados à Mobilidade Aérea Urbana**. In: WORKSHOP DE COMPUTAÇÃO URBANA (COURB), 9. , 2025, Natal/RN. Anais [...]. Porto Alegre: Sociedade Brasileira de Computação, 2025 . p. 321-334.

Permissioned Blockchain in Advanced Air Mobility: A Performance Analysis for UTM

Rodrigo Nunes*, André Melo*, Rafael Albarello*, Reinaldo Gomes†, Cesar Marcondes*, Lourenço Pereira Jr*
*Computer Science Division, Aeronautics Institute of Technology, Brazil
†Brazilian National Research and Educational Network, RNP, Brazil
{andre.melo,albarello,rodrigosergio}@ita.br, reinaldo.gomes@rnp.br, {cmarcondes,ljr}@ita.br

***Abstract*—The integration of Uncrewed Aerial Vehicles (UAVs) into low-altitude airspace has led authorities to adopt distributed Uncrewed Traffic Management (UTM) architectures that ensure interoperability and safety. Blockchain has been proposed as an enabler for trustworthy coordination among UTM stakeholders. Yet, its real-time performance under aeronautical constraints remains insufficiently characterized. This paper presents a quantitative benchmark comparing two regulation-compliant distributed architectures: the federated InterUSS platform maintained by the Linux Foundation and a permissioned blockchain based on Hyperledger Fabric. Both systems were evaluated through Operational Intent Reference (OIR) registration workloads generated via Hyperledger Caliper, measuring throughput, latency, and transaction loss under loads up to 50 transactions per second. Results show that InterUSS sustained sub-second latency and stable performance up to 30 TPS. At the same time, Fabric exhibited exponential degradation with median latency exceeding 3 s and tail latencies above 15 s beyond that point. These findings demonstrate that blockchain-based architectures must be redesigned to meet aeronautical timing and scalability requirements, suggesting that hybrid models combining distributed ledgers for auditability with federated frameworks for real-time coordination are more suitable for future UTM deployments.**

***Index Terms*—UAV, UTM, blockchain, Caliper, Fabric, Interuss**

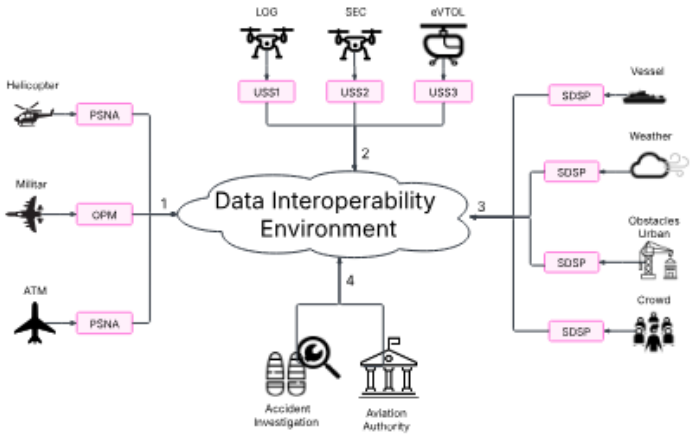

Figure 1: Data Interoperability Environment

scalability, making them unsuitable for aeronautical-grade reliability. To ensure interoperability among multiple USS while avoiding centralized dependencies, the *InterUSS Platform* was introduced as an open and federated data-exchange framework

NUNES, Rodrigo Sergio dos Santos; MELO, Andre Elias; ALBARELLO, Rafael Hickman; GOMES, Reinaldo Cezar de Morais; MARCONDES, Cesar; PEREIRA JUNIOR, Lourenço Alves. **Permissioned Blockchain in Advanced Air Mobility: A Performance Analisys for UTM**. http://arxiv.org/abs/2511.02171

OBRIGADO

GT DRONECHAIN-UTM

André Elias Melo, **Rafael Hickmann Albarello**, Rodrigo Sérgio dos Santos Nunes, **Lourenço Alves Pereira Júnior**

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Blockchain em evolução.